Biotechnology:

A New Fundamental in the Training of Engineers

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TEACHING AND RESEARCH ON THE human problems of engineering have been inaugurated as fundamental activities in the Department of Engineering, University of California. This program, which represents an effort to develop a biotechnology as a basic discipline in engineering education, embraces those features of human physiology, psychology, and hygiene which are pertinent to engineering practice. Implicit in the plan is the recognition that the conditions and trends of modern life involve in increasing degree the following sociotechnological elements: (1) the interdependence of man and machines, (2) the progressive extension of artificial control of human environment, and (3) the expanding role of the engineer in human affairs. Engineering practice, it is our conviction, will demand a much more precise formulation of human characteristics for its part in the solution of these problems: in short, a biotechnology to take its place with the physical technologies which are the bulwark of engineering training.

In this era of rapid expansion in engineering application of the diverse products of science, there is continuing pressure for the addition of new technical specialties to the already saturated engineering curriculum; consequently, it is clear that any curricular innovation must fully justify itself on practical as well as philosophical grounds. We believe, however, that the time is right for the addition of a biological phase to the technological equipment of the engineer, and here set down the reasons for this development.

The Substance of a Biotechnology

In many phases of engineering, essential design criteria are based upon human physiological characteristics. Ventilation is in part based on respiratory needs and, jointly with heating and air-conditioning, serves the needs of body-temperature regulation and thermal comfort. Illumination requirements depend fundamentally upon the properties of the visual sense. Indeed, all aspects of environmental control, including also noise abatement, reduction of bacterial, physical, and chemical contamination of the air, and functional aspects of industrial design, take their origin from human needs and tolerances. These elements of environmental hygiene, well recognized in engineering practice as it concerns public and industrial buildings, extend now to the home and to transportation vehicles.

The structure of the human body, both statically and dynamically, is often an important consideration in engineering design. Applied anthropometry finds important utilization in aircraft cabin appointments, machine design, and comfort seating. Recent improvements in amputation prosthesis may be credited to the collaboration of engineer, physican, and limb fitter. Here, the engineer performs invaluable service through application of his knowledge of analytical mechanics and the strength of materials. Similar training and experience is useful in determining structural limitations in the human body relative to design of safety harness, such as is used by the steeplejack and by the military aircraft pilot. These problems point to the need for a systematic structural analysis of the human body, and it is but a short step to incorporate the study of anatomical materials, paralleling instruction in engineering materials.

The capacity, efficiency, and endurance of the human machine in physical labor is the concern of every engineer who assumes administrative duties, and doubly so for the production engineer. These factors underlie the principles of scientific management and time-and-motion analysis. When the additional stresses of environmental temperature, pressure, or anoxia accompany the work, physiological tolerance may be a critical concern. Hours of work, on-the-job feeding, rest periods, etc. are also phases of the physiology of work which form an important part of a comprehensive biotechnology.

Understanding of the principles of human psychology, with special reference to industrial and technological pursuits, is a prime objective of the program. Compton (*1*) points out that the engineer is usually a member of an organization, whether industrial, service, or governmental. Accordingly, the ability to work effectively with others is important to his personal success, as well as to that of the organization to which he belongs. Two-thirds of engineering graduates enter business or industrial careers primarily concerned with production, operations, sales, and management. Indeed, by the age of forty, 60 per cent of engineering graduates find themselves in positions of administrative responsibility. What more striking evidence is needed of the fact that the engineer handles men as well as machines and materials! To implement the need for better training of engineers to assume leadership in practical, on-the-job human relations, the standard phases of psychology, such as motivation, learning, social behavior, perception, and emotion, must be applied to such practical problems as industrial relations, job training, personnel management, and wage and hour policy.

The biotechnical program contributes also to a prominent contemporary aim of the profession, namely, to broaden the base of engineering education to include humanistic-social studies (*3*). These studies, in contrast to physical sciences, mathematics, graphics, and other technics, which constitute the essential core of the curriculum, aim at a better understanding of social, economic, and cultural values, and the development of moral and ethical concepts essential to public welfare. Their importance in the education of the engineer derives from the facts that technological developments exert a profound effect upon modern civilization, and that the engineer occupies an increasingly responsible position in the socioeconomic instrumentalities of this evolution.

In early times the engineer was a surveyor, a builder, or a shop owner. With the advent of the modern industrial structure, with its need for technical invention and control, and technological extensions into the fields of communications, transportation, amusement, and the home, the engineer functions in the management, control, and direction of both process and personnel. He has thus become an important instrument in shaping the social and business economy, and it is to fit him more adequately for this role that the humanistic-social studies are advocated.

Biotechnical Studies and the Engineering Curriculum

The impartial but critical reader, while granting the necessity for a biotechnology, may yet raise two questions, one fundamental and the other practical: (1) Is it the proper function of the engineering department to sponsor biotechnical studies? (2) Will not the addition of such studies seriously burden the engineering curriculum?

The first, concerning academic sponsorship, may in part be answered in the words of Wickenden (*2*):

> Looking to the future, the schools of engineering can scarcely limit their concern to the mathematical and physical sciences, to problems of design and construction, and to the specific details of engineering economy. Engineering will include in its tools any and all sciences as they become exact enough to yield economically predictable results. Various aspects of biology, especially bacteriology, are being incorporated into the working tools of engineering now, and technical psychology is fast approaching a similar stage of development. To fit new scientific materials into the scheme of engineering education involves more than a mere addition of conventional courses in zoology, physiology, bacteriology, or psychology to the curriculum. The new material needs to be functionalized. A large amount of practical research is still needed to work up biotechnics and psycho-technics into trustworthy tools of engineering.

Thus, biotechnology rightfully falls within the scope of engineering practice, considered in its broadest sense. While the physical sciences have traditionally formed the basis of engineering, and it is the common view (indeed, among most engineers themselves) that engineering deals solely with machines, processes, circuits, and structures, theorists agree that the functions of the engineer should be defined less in terms of conventional fields of application than in terms of the method he employs in solving the technological problems of society. It is, therefore, both logical and practical that a biotechnology should develop within the framework of engineering training and practice.

In part, the study and practice of biotechnology is left to engineering by default of other educational and professional agencies. The elements of human biology are now dispersed among the academic sciences of physiology, psychology, anatomy, biology, and physical anthropology. While the field of human biology has certainly suffered much from lack of an integrated treatment as an academic discipline in its own right, the greater fault lies in the fact that society has not found a place, except for medicine and its related pursuits, for an applied science of human biology. It would be gross injustice to minimize the biotechnological contributions of workers in the established academic sciences, much less the services of the organized professions of industrial medicine, industrial psychology, and safety engineering. Rather, we desire to emphasize the errors of omission, to point out the defects resulting from lack of a formal systematization of biotechnology. These are: (1) the comparative scarcity of manuals, text materials, and other media for diffusing the known and pertinent facts of human biology to properly qualified technical personnel who can apply this information; (2) the existence of substantial gaps in technology, which would disappear with practical research oriented to the needs of a general biotechnology. For example, to the writers' knowledge, there does not exist today a manual of human design standards for engineers; (3) the lack of any recognizable course of training, in the universities or elsewhere, for a general biotechnical specialist, and inadequate appreciation of the benefits which would derive from application of such a specialty. This does not mean that the need does not exist but that biotechnological functions either are being performed by inadequately or narrowly trained individuals or are neglected entirely.

Addition of new courses, such as the biotechnologies, to the engineering curriculum raises a further problem. Many engineering educators maintain that basic engineering training should be accomplished within the four-year baccalaureate program, yet a rapidly expanding array of technologies creates a continuous demand for inclusion of new specialized courses in the curriculum. However, it would be literally impossible to foresee and provide for all the varied careers which engineers ultimately pursue, and the details of final occupational adjustment must be left to on-the-job training. This principle is now supported by industry as well as engineering educators. Graduate engineers who have advanced and specialized technical interests or who elect an academic career in engineering teaching and research are provided for in the graduate program. Thus, we may define undergraduate engineering education as one of "practical fundamentals," set between the extremes of pure science and technological practice. This level is achieved less by simplifying the treatment of scientific material than by careful selection and emphasis of those elements which have practical utility, and which, further, are common to many applications.

In keeping with this plan for general engineering education, we seek to pitch the biotechnical studies on the "practical fundamental" level, avoiding the minutiae of biological science which have no immediate utility, but stressing those features of human biology and psychology pertinent to industry and general engineering practice.

A Plan for Biotechnical Training

(1) *Fundamental courses.* Basic in the program are two courses which cover the pertinent facts of human biology and the interaction of man with his environment in as concise, quantitative, and practical a fashion as the present status of science permits. The first of these courses, The Dynamics of Human Function and Behavior, deals with the physical structure, thermodynamics, and machinery for the accomplishment of work of the body, and with practical psychology. The second, The Influences of Environment on Man, treats of his interactions with atmospheric, thermal, bacterial, radiational, and chemical aspects of the environment, and also the socioeconomic setting. It may be noted that certain topics are predominantly physical and physiological, others psychological; but in so far as possible, an attempt will be made to avoid the common but regrettable separation of these aspects and to integrate them in the most rational manner possible.

(2) *Applied instruction and research.* The possible ramifications of the biotechnical element throughout engineering research and practice are almost infinite, but it will suffice here to name some of the engineering fields in which the basic human aspect is of significant importance in design and control:

Acoustics	Industrial hygiene
Aeronautics	Personnel management
Architecture	Safety
Food technology	Sales
Illumination	Sanitation
Industrial design	Ventilation and air-conditioning
Production and fabrication	

It is our hope that the engineering student, prepared by instruction in the biotechnical courses, may approach these advanced specialties with as fundamental an understanding of the biological factors involved as he would undertake an advanced structural design problem with a background in mechanics and strength of materials. The biotechnical elements will also serve as the foundation for applications in other engineering courses. As examples, the effect of vibration on the human system will be incorporated into dynamics courses, skeletal kinematics and dynamics will underlie the study of certain nonmechanized operations, and the fields of acoustics and illumination will be placed upon psychological and physiological bases as well as the physical basis. Thus it will be sought to interweave the biotechnical material throughout the engineering curriculum.

(3) *Problems and prospects.* Above we have outlined the need and set forth the philosophy and first practical steps. The detailed evolution of the program will depend upon experience with its application. It may be expected that progress in science, on the one hand, and trends in technology, on the other, will alter the instruction in general biotechnology and determine the nature of specialized research and applications. It should be emphasized that our primary objective is to broaden the training of the engineer rather than to inaugurate a new engineering subprofession. It is not contemplated that this training will introduce professional conflict between the engineer and the industrial surgeon, toxicologist, or physiologist, the need for whose specialized services in industry remains unchallenged. Rather, the aim is to produce engineers, well prepared with respect to every technical requirement, but with additional competence for dealing with man whether on the structural-functional level or the humanistic-social level.

References

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3. ——————. Report of the Committee on Aims and Scope of Engineering Curricula. *J. eng. Educ.*, 1940, **30**, 555.