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GENERAL ASPECTS OF INTERDISCIPLINARY RESEARCH IN EXPERIMENTAL HUMAN BIOLOGY[1]

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INTRODUCTION

MUCH of the recent research in experimental human biology using a "total" interdisciplinary approach has received methodological stimulation from the attempt to predict what will happen, under specified conditions, to the intact human organism. In such a program the experimenter works with one "independent" variable (environmental temperature, caloric intake, vitamins, drugs, anoxia, physical work) and many "dependent" variables covering the whole gamut of biochemical, physiological and psychological responses. This type of research differs fundamentally from much of the earlier work in psychosomatics,[2] such as study of the covariation between morphological characteristics and mental traits in which statistical methods provide the sole method of investigation. The study of the effects of vitamin intake or exposure to heat is amenable to the experimental approach, also such problems are much closer to real life situations and require a more truly interdisciplinary attack.

In applied fields a genuine cooperative approach is indispensable. This is readily understandable if we realize that the emphasis is placed upon analysis and manipulation of a sector of reality, and that this reality is always multifarious. It is significant that, in modern industrial research which is concerned with the materials and the manufacturing processes, "the lone worker is being replaced by a carefully chosen corps whose various talents dovetail together and whose collective knowledge and collective analytical

[1] From the Laboratory of Physiological Hygiene.

[2] D. G. Paterson, "Physique and Intellect," New York, Century, 304 pp., 1930.

powers greatly exceed those of any single member of the group."[3] In human biology, as well, the main pressure for interdisciplinary orientation comes from the applied field. The workers in a child guidance clinic, for example, have to draw upon psychology, psychiatry, medicine, education and sociology, each of these making an important contribution to the practical working of the clinic.[4]

The investigation of the problems of human work and nutrition, research on color and sound, studies of heredity, of growth and ageing and of many other topics belonging to the field of a broadly conceived human biology yield more significant results if two or more research workers, representing different fields of specialization bearing on the particular problem, work together in a close coordination. Thus McCay, referring to gerontological work, expressed the need for pursuing a line of attack in which the physicists, biochemists, bacteriologists, nutritionists, pathologists, physiologists, histologists and psychologists work side by side: "Little hope of progress in studying the process of ageing can exist until special institutes of research are established in which whole groups of specialists will devote their lives to cooperative attempts to solve the intricate problems."[5]

Personnel Requirements

The process of scientific discovery, especially as developed in group-research, is an intriguing sociological and psychological problem. Sociological studies of human interaction which takes place in the process of scientific research reveal all basic behavior patterns (individualistic, competitive, exploitative, cooperative) which can be found in the entire field of human relations.[6, 7]

Psychologically, cooperative research has as one of its first prerequisites the sharing of some amount of factual knowledge and methodological ideas by the interacting parties. This point was brought out by Maurice L. Huggins in discussing investigation of the problems located in the borderland between biology, mineralogy and physical chemistry. He emphasized that one important condition for an effective interdisciplinary research is that "each of the cooperating scientists must have or must secure an understanding of the language, the problems, and the research methods of the other."[8] This widening of the horizon requires added expenditure of time and effort, but it pays dividends.

The reciprocal acquaintance with the methodological characteristics of the participating sciences is an important component of effective interdisciplinary cooperation. If the psychologist does not even have a remote idea of the conditions under which biochemical data are obtained—*e.g.*, how much time and care in studies of "physical fitness" it takes to make a determination of respiratory quotient or of lactic acid concentration in blood—he can not participate intelligently in planning a cooperative research program. The biochemist, on the other hand, must acquire a respect for standardization of psychological experimental conditions which differ from those of chemistry. One can curse the flame and nothing much happens—if one doesn't blow too hard. This seems trivial, but the methodological differences and peculiarities are not self-evident: the physiologist must learn to appreciate the fact that the presence of another person in a room where psychological testing is being done can make a difference and, under certain conditions, can invalidate the results.

In addition to a certain amount of common intellectual background, personality characteristics basic to team work as well as skills in cooperative planning, execution of the experiment and formulation of results are important. Some of the skills which facilitate cooperative research are identical with those required for any genuine group participation. Dr. May stressed the technique of careful and sympathetic listening to the contribution of each member of the group. The role of an active listener alternates in a discussion with that of an active talker and results in equilibrium between dominance and submission.

Successful execution of cooperative research requires modification of the competitive work habits which have been fostered by the hyper-individualistic philosophy of life expressed in the traditions of university research. University departments "compete for students, required courses, budget, size of staff, promotion of members, funds for research, space for offices and classrooms, and above all for prestige"[6] and this competitive spirit creates a barrier to interdepartmental work. A second barrier to interdepartmental cooperation is seen by Dr. May in the positional system within each department; the young scientist has a greater chance of advancement if he saws wood on his own wood pile, follows the traditional paths and works for the greater glory of his department and does not participate in interdepartmental, collaborative projects. The third barrier is formed by a set of traditional attitudes and ideas such as the

[3] F. B. Jewett and R. W. King, SCIENCE, 92: 365–371, 1940.

[4] C. M. Louttit, "Clinical Psychology, A Handbook of Children's Behavior Problems," New York, Harper, 695 pp., 1936.

[5] C. M. McCay, "Problems of Ageing," E. V. Cowdry, ed., pp. 572–623, 1939.

[6] M. A. May, "Cooperative Research," Yale University, Ms., n.d.

[7] We wish to express our gratitude to Dr. May, director of the Yale Institute of Human Relations, for making available to us the manuscript of his stimulating paper on "Cooperative Research."

[8] M. L. Huggins, *American Scientist*, 31: 338–345, 1943.

belief that scientific discoveries are always the products of individual minds, or that the cooperative setting limits the freedom of the scientist to follow the dictates of his own intellectual curiosity. The fourth barrier is a result of university training in individualistic work habits.

Thus the young scientist, who grows up in the midst of a competition between university departments and amidst competition within his department, who inherits the individualistic research tradition and graduates without having had an opportunity to develop skills in cooperative thinking and collaborative study, is poorly prepared to participate in the activities of a committee or a research team. He may have become skilful in gathering empirical data within his narrow field of specialization, but his techniques of social interaction are underdeveloped and ineffective in a practical test situation.

Because of the obstacles which stand in the way of interdepartmental research, it appears that interdisciplinary work, at least at the present time, can be carried on more effectively in institutes expressly organized for that purpose. However, these should by no means be cut off from the rest of the university. Pioneering work in this direction has been done at Yale where, in answer to the need for bridging several "anthropological" disciplines, the Yale Institute of Human Relations was created more than a decade ago. President Angell, in introducing the institute, stated that it was the result of a natural evolutionary process in which a number of separate academic groups have come to recognize their common interests and the advantages of prosecuting them cooperatively: "The purpose is to correlate knowledge and coordinate technique in related fields, that greater progress may be made in the understanding of human life from the biological, psychological and sociological viewpoints."[9] This was an important development even though not all the high hopes placed in the effectiveness of the new organization have materialized. Since 1930 other university institutes have been organized along interdisciplinary lines, although the development in some areas such as research on human work[10] has been slower than abroad.

TRAINING PROGRAM

Both competitive and cooperative behavior patterns are acquired in the process of learning. Neither is innate nor representative of the "true" nature of man.[11] The universities, yielding to requests for research workers and technicians with talent for teamwork, will have to provide training facilities which will emphasize the collaborative techniques both within and between allied departments. Over and above this pressure from the outside, there are important scientific grounds why interdisciplinary (and interdepartmental) research should become a greater concern of the universities. The assertion that institutes of an interdisciplinary character will be associated more often with industrial enterprises than with universities may be correct in the statistical sense, but it should not imply that cooperative research is an industrial prerogative.

There are two very serious reasons why the inclusion of this new research form should be a part of graduate schools: Numerous problems of a fundamental theoretical character which require a cooperative approach are not likely to be studied by industrial laboratories the very existence of which often depends upon immediate, practical results. The second reason is still more important. Industrial organizations only very rarely will provide the time and personnel to carry out a training program of high academic standards. There must be a genuine interest in acquainting the student with the full breadth and depth of the interdisciplinary research problems, which implies a full freedom to explore aspects other than those which belong to the student's immediate field of specialization. The most adequate "climate" for the training of graduate students in coperative research is a place in which such an approach is actually practiced, because there is no substitute for the method of learning by doing. At the same time, the institution in charge of the training program must be well aware of its scientific and social responsibilities and must provide stimulating supervision which is or should be a distinguishing feature of student-teacher relationship on the graduate level.

There can be much improvement in the undergraduate curriculum in the sense of broadening the background of the student and building a more interrelated sequence. Progressive education in this country has been experimenting with this idea for some time. At the University of Minnesota the attempts in this direction are closely related to progress in the field of "general education." This term usually has a broader meaning than providing a well-rounded scientific background and refers to the educational processes which aim at the development of insight, appreciation and skills needed for effective participation in a democratic society.

In terms of a committee report by Ruth E. Eckert and Horace T. Morse, general education "should give the individual an answer and understanding of problems of contemporary living, the cultural, social and technological heritage of his age, and develop in him the ability to think critically, to weigh basic human

[9] J. R. Angell, *Educational Record*, 11: 3–11, 1930.
[10] J. M. Brozek, *Federation Proc.*, 2: 134–144, 1943.
[11] M. A. May and L. W. Doob, *Bull.* No. 25, Social Science Research Council, April, 1937.

values, and to appreciate the product of creative thought and expression."[12] These aims are as valid and as important in the preparation for a scientific career as in the training of citizens for other walks of life. The idea of "general college" within the university has been offered as a means to these ends. There is a danger, of course, that the general college may serve as a refuge for those students who are unwilling or unable to pursue intensive studies. It would be unfortunate if the "general college" should simply provide a dumping ground for less capable students.

General education on the university level should (1) broaden and integrate the scientific training of the student and (2) contribute to his personal and social development. We agree with Maurice B. Visscher, when he says that the instructional staff in charge of the integrative scientific courses should be made up of *bona fide* scholars in the areas discussed. Frequently it will be difficult to find a single person with the necessary knowledge and teaching experience who could competently handle such courses. The logical alternative is a cooperative teaching program which would put into full use all the human resources of a university. "It is . . . recommended that where necessary new types of functional organizations of small groups of scholars drawn from several conventional areas of specialization be set up and that existing arrangements of this type be extended to implement the program of general education."[13] Visscher uses this approach on the graduate level in a systematic two-quarter course on Human Physiology at the University of Minnesota. General Psychology, given by Richard M. Elliott together with other members of the department, follows a similar pattern in a three-quarter course at the same university.

The problem of greater integration of college work has received serious attention at the University of Chicago. It was realized that the departmental organization "has great advantages in the training of men for specialized research and teaching in conventional and well-established fields," but "at the same time, it promotes narrowness in research and does not encourage the student to get an education broad as well as deep."[14] The consolidation of independent departments into the larger divisions (biological, physical and social sciences, and humanities) has been an important step. The next step in the direction of giving the university student a broader background has been the establishment of the Junior College which would supply an education basic to the work of all divisions and professional schools. The purpose was ". . . to mitigate the evils of premature specialization and to unite both the students and faculty in a community the members of which could have some hope of understanding each other."[14] Further arrangements are being made on the graduate level to provide an opportunity for study and research of a significantly broader scope than has been previously acceptable.[15]

The program of the Minnesota group includes the experience of working cooperatively with others as one of the purposes of general education. On the graduate level there should be provision for training in group discussion and group reporting, the use of panel presentation of seminar topics should be especially encouraged. Interdepartmental seminars will give the student opportunity to get acquainted with current research topics and methods. One of the techniques which might be used to promote cooperative research is an interdepartmental exchange of young instructors.

A meaningful course in the philosophy of science could contribute significantly to preparation for cooperative research. The situation prevailing at the universities is not far from a farce. Scientific methodology is discussed in philosophy departments where the students know of contemporary scientific research work, for the most part, only from hearsay. On the other hand, students in scientific fields learn specialized techniques but are not motivated to look beyond their own hunting grounds and underneath the surface of the "facts." We have in mind a genuine theory of scientific knowledge which should include (1) semantics—the theory of meaning and the study of verbal and non-verbal symbols used in representing scientific concepts and their combinations, (2) logic of the scientific method which deals with experimental design, collection of data, analysis of the error of measurement, process of inference and testing of hypotheses and (3) "concrete" logic or systematology of the sciences based on the analysis of their subject-matter and methods used.

For the research worker who has grown up in the traditional departmentalized university and who is anxious to take part in interdisciplinary work, the first step is to get a bird's-eye view of the neighboring fields and to obtain familiarity with the problems which are currently the foci of interest. However, text-book acquaintance is not enough; some contact with actual work methods is essential. Because of the expanse of each scientific discipline, emphasis should be placed on the methods which are actually used or

[12] R. E. Eckert and H. T. Morse, "General Education at the University of Minnesota." Mimeographed report, n.d.

[13] M. B. Visscher, "The Techniques of General Education Courses and Their Implications for Scholarship in the University," University of Minnesota, Ms., n.d.

[14] R. M. Hutchins, *Alumni Bulletin*, November 1, 1943. 23 pp.

[15] J. U. Nef, "Memorandum Concerning the Field of Social Thought," Univ. of Chicago, 4 pp., n.d.

may be used in exploration of the territory inviting an interdisciplinary approach. A benevolent tolerance is a prerequisite, but significant work can grow only out of an active cross-fertilization of scientific minds. This constitutes a very different process from presenting incoherent, parallel, non-integrated reports at a meeting of specialists.

A CASE HISTORY

It may be useful to round out our discussion and to give it more reality by presenting in greater detail an interdisciplinary institute, the Laboratory of Physiological Hygiene at the University of Minnesota.

The laboratory is carrying on research in the field of a broadly conceived physiology. This includes (1) biophysics, in the larger sense, involving the study of kinetic (circulation, respiration) and electric phenomena, (2) biochemistry (metabolism, composition of food, blood and excreta), and (3) behavioral psychology covering the sensory, motor and intellective aspects, and personality.

The organization of the laboratory is built up on the conviction that a meaningful attack on the major problems of applied human physiology requires a cooperative approach. Thus physiologists, biochemists and psychologists, together with technical assistants, work as a team under the coordinating effort of a director-colleague. For many problems it is desirable to have ready consultation with members of other university departments—clinicians, physicists, chemists and engineers. The laboratory has established such collaboration as contributes materially to the scope of the problems that can be handled.

From the point of view of social organization the general scheme of the laboratory can be labeled as a "director-staff" plan. The head of the laboratory is in charge of the budget and administration, and is responsible for the general direction of the work program and the selection of major research topics. However, the staff has ample opportunity to exhibit initiative in deciding on specific action and alternatives and in selecting definite variables and techniques to measure them.

On the basis of these suggestions a general research plan is drawn up and discussed in staff meetings. The daily experimental routine is determined in minute detail, a factor of importance in long-term nutritional cooperative studies which are to meet the requirements of a rigorously controlled experimental work. Once the overall plans are laid, the execution of specific parts of the program is an individual responsibility. Staff meetings in which progress reports are presented provide the medium of integration.

Cooperative research does not mean less individual initiative or less personal responsibility. In this respect the laboratory differs distinctly from large industrial research organizations where a complex practical problem is frequently broken down into a number of researches each dealing with a single independent-dependent variable pair. The results are then synthesized by a research director who may have little contact with the separate studies. The individual research workers have little grasp of the problem as a whole and may lose sight of the ultimate aim, if, indeed, they are aware of the goal. They tend to be semi-automatic technicians only. The most fundamental objection to this method is the initial necessity for completely accurate coverage and definition of all constituent problems, and the frequent unpredictability of the behavior of the several variables when they are operating in a complex system.

Informal evening meetings of the senior staff appear to offer a particularly valuable opportunity for genuine group discussion and group thinking. Two cooperative undertakings which are still in a state of flux comprise the development of a central bibliographical file and a file of excerpts. When a staff member compiles a bibliography on a specific topic which covers a current or possible future research subject, a set of duplicate cards is made for the central file, accessible to all members, which remains a permanent possession of the laboratory. It is also planned to have a common catalogue of reprints which are the property of the individual members.

Although the main emphasis is on collaborative research (see *e.g.*,[16, 17]) the individual staff members have opportunity to pursue their scientific curiosity. There is opportunity for individual research especially if it contributes new techniques or clarifies the "background" or "foreground" of the larger work. The investigations of the effects of nutrition on the adjustment to high temperatures may be cited as an example.[18] In a "sideline" project, the physiologists studied intensively the problems of cardiovascular adjustments during exposure to dry heat.[19] The composition of sweat, an important factor in interpreting these changes, was investigated by the biochemist.[20] The psychologist utilized some of the data on functional efficiency of the human organism exposed to experimental strain (heat and hard work) in a syste-

[16] A. Keys, A. F. Henschel, O. Mickelsen and J. M. Brozek, *Jour. Nutrition*, 26: 399–415, 1943.

[17] A. Keys, A. F. Henschel, O. Mickelsen, J. M. Brozek and J. H. Crawford, *Jour. Nutrition*, 27: 165–178, 1944.

[18] A. Henschel, H. L. Taylor, J. Brozek, O. Mickelsen and A. Keys, *Jour. Trop. Med.* (in press), 1944.

[19] H. L. Taylor, A. F. Henschel and A. Keys, *Am. Jour. Physiol.*, 139: 583–591, 1943.

[20] O. Mickelsen and A. Keys, *Jour. Biol. Chem.*, 149: 479–490, 1943.

matic study on flicker fusion frequency as a test of fatigue.[21]

In the early stages of the development of the laboratory full-time participation of all staff members in the research program was necessary. It would appear advantageous that senior staff members of the laboratory should have formal appointments on a part-time basis in the respective departments of their basic interests. Such arrangements have now been made so that the senior biochemist devotes one fourth of his time to teaching responsibilities in the department of biochemistry, and so on. In addition, the laboratory as a unit should have certain definite teaching responsibilities. Through teaching a wider range of topics is covered than in specialized research and this helps to keep open the intellectual horizon. Then, too, a more direct contact with members of the "home" department should provide opportunity for further intellectual stimulation. The spirit of interdisciplinary research work, on the other hand, can be best transmitted to the students by persons who live and breathe in a cooperative atmosphere. Arrangement for internships and participation of graduate students in the research should be facilitated in this way.

An institute organized along the lines of this laboratory may play a particularly significant role in medical education. Organization of research and teaching in medical schools obstinately tends to follow the departmental structure. Also, the research is frequently limited by dependence on facilities supplied primarily for pedagogical purposes in the basic science departments and for direct diagnostic and therapeutic purposes in the clinical departments. Medical schools are commonly very inadequately equipped and methodologically not prepared for the study of important behavioral aspects of human adjustment mechanisms. This is partly due to the fact that in the orthodox medical curriculum there is, for the most part, no provision for the study of the individual human organism as an integral of anatomical and histological structures, biochemical reactions, biophysical processes, psychological motives and conditioned responses.

In the fundamental sciences the medical student is encouraged to think in terms of quantitative data, controlled conditions and experimental approach. The variables are well isolated and behave pretty much as the textbook suggests. When the student is faced with the complex organism he is apt to overcompensate for the feeling of inadequacy by calling too readily upon "intuition" when the situation calls logically for a simultaneous application of different methods covering many variables. It is realized that the step from the formal, rather abstract knowledge in the fundamental sciences to the scientific analysis and grasp of the complex problems of the patient is a difficult one. The staff of an interdisciplinary laboratory can be of much service in providing integrative lectures and seminars and detailed demonstrations. Such a laboratory presents opportunities to interested advanced students for more realistic laboratory work than is customarily available in physiology, biochemistry and psychology. Participation of graduate students and of medical graduates in the work of the laboratory should be very useful as a final preparation for both teaching and research.

Conclusions

The interdisciplinary approach is becoming one of the prominent characteristics of experimental human biology and represents a synthesizing trend which focuses the specialized research techniques on problems common to a number of separate disciplines.

Such a cooperative research has to overcome serious obstacles when operating within the existing departmentalized framework of the universities. It appears that real progress in this direction will be made in institutions which are organized on a permanent and frankly cooperative basis.

Psychologically, interdisciplinary research requires not only abstract, theoretical intelligence (and, frequently, manipulative skill) but also "social intelligence." Cooperative work is a social art and has to be practiced with patience. A team of research workers representing various disciplines can be welded into a fully integrated unit only on the basis of extensive experience of working and thinking together.

In the training program three points deserve emphasis: (1) facilities for getting acquainted with the problems and methods of the neighbor fields, (2) study of the "science of science" which provides the necessary philosophical perspective, and (3) development of social skills required for a stimulating and efficient scientific cooperation.

[21] J. Brozek and A. Keys, *Jour. Indust. Hyg. Toxicol.*, 26: 169–174, 1944.

OBITUARY

I. HUANG

A CABLEGRAM reports the recent death of I. Huang, professor of psychology in the National University of Chekiang, Tsunyi, Kweichow, China. This brings to an untimely close a valiant career which achieved much under great obstacles and which promised yet more for the New China and for intercultural relations with America.