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BORDERLANDS IN SCIENCE[1]

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THE PROBLEM

THE conventional classification of knowledge into the several organized categories, such as physics, medicine, biology, etc., is merely an artificial device largely for our convenience; a device that, unfortunately, tends to emphasize the difference between bodies of knowledge and in consequence minimizes unduly their similarities. Knowledge itself is continuous; its growth means multiplication of categories. Out of the old natural philosophy we carved chemistry, physics, botany and zoology. Within chemistry we now recognize such subdivisions as inorganic chemistry, organic chemistry, colloid chemistry and the like.

In general, these subdivisions within a given field are well sponsored by the parent science. With the growth of knowledge there comes inevitably the development of important fields lying between sciences. Some of these fields are adopted by one of the contiguous sciences; thus we have physical chemistry within the field of chemistry and astrophysics largely within the field of astronomy. Other of these subjects frequently develop into sciences which attain almost an independent status, as is illustrated by biochemistry.

There is, however, between the conventionally recognized divisions of science an extensive "no man's land," many parts of which are of great importance but which, for want of adequate sponsorship and because of certain inhibitions in connection with re-

[1] These observations are drawn largely from the discussions of this subject in meetings of committees of the National Research Council during the past year. They are presented not as a special statement from the Council, but as an individual article with the hope on the part of the author of eliciting further comment from others who may be interested in this matter.

search therein, either are slow in developing or are not cultivated at all.

In the development of these borderland fields there are frequently met difficulties which are not encountered within the limits of established fields. Frequently, as for example in the case of biophysics, progress can be made only by the cooperative efforts of two or more persons or groups of persons of very different training and view-points. The biologist is keenly conscious of the importance of the application of physical methods and principles to the study of biological phenomena; and he naturally turns to the physicist for help. The physicist, however, is very frequently engrossed with fundamental problems in his own field which are so fascinating as to take his entire attention. Furthermore, the training of the physicist in the more or less quantitative methods of the physical laboratory tends to unfit him temperamentally for the type of research, much more qualitative, of the biological laboratory.

These differences and difficulties are greatly accentuated by the fact that the two groups of scientists concerned are in general linked to different administrative departments of a given university or other institution, and it is not always easy to cut across these artificial lines of organization. Then, too, the younger scientists not infrequently feel that they are "losing caste" with their colleagues when they enter borderland fields. This attitude finds some justification in the fact that, until a given borderland field develops to the point of being generally recognized by administrative provision therefor, it is not easy for a young man entering such a field to secure a position.

In view of the importance of these several borderland fields and of the impediments, natural as well as artificial, in the way of their development, it becomes a question of some little importance to research and educational administrators to decide how this type of research can best be fostered. Granted that numerous such borderland fields exist, should efforts be made (1) to take the initiative deliberately in surveying the whole "no man's land" of science and select here and there fields which should be cultivated, and take such means as are available for such cultivation; or (2) should a policy of "watchful waiting" be adopted with view to lending encouragement to any individual or group of individuals who are working in such borderland fields; or (3) should an intermediate position be taken between these two extremes by being ready to offer assistance, so far as may be possible, to any group of workers within a given field of science who in the prosecution of a definite research program find that such program leads into the "no man's land."

Whatever the ultimate decision—if indeed any decision as to policy be possible—it is generally recognized that no worthy research program in a borderland field should be allowed "to fall between two stools" merely because it does not happen to be classified within any one of the conventional divisions of science. It should, however, be recognized that "science planning," particularly in borderland fields, should be very carefully done. Henry James, in his "Life of Charles William Eliot," records that while still a young man Eliot wrote a new text-book of chemistry and in the introduction took pride in stating that whereas previous books on chemistry had tended more and more to introduce physical elements he had eliminated those elements and made *his* book a text-book in pure chemistry!

Whatever policy is to be followed in its relation to borderland fields, it is obvious that institutions, just as an individual should do, should constantly be alive to the importance of self-study so that they may avoid the dangers of running in ruts and of allowing their procedures to become unduly crystallized.

This question of borderland fields is recognized as of special importance in university organization. It is beginning to be more generally recognized that the organization of universities into colleges and departments inhibits to a certain extent not only the development of science but the natural evolution of educational programs. To remedy such inhibition the University of Minnesota, for example, has organized a university college with a dean and faculty made up of a selected list of professors representing collectively practically all the fields of knowledge within the whole university. A student whose interests cut across the lines of university organization is registered in this university college and is put under the direction of a special committee which outlines his program of study and, in due course, awards to him the appropriate degree.

Activities of the National Research Council in Borderlands in Science

The National Research Council has already engaged extensively in the cultivation of borderland fields of science. Since the problem may be analyzed more adequately in terms of concrete projects and problems, a few illustrations will be given of the many borderland problems and fields to which the Council has already directed its attention.

Under the Division of Geology and Geography there is a Committee on the Measurement of Geological Time, which enlists the resources of geologists, physicists and chemists in its effort to measure geologic time by the rate and degree of disintegration of radioactive minerals. Geologists and mineralogists furnish the raw material for this study. Chemists determine the amount of radioactive lead present in the samples, and

from a knowledge of the rate of production of such lead determined by both physicists and chemists information as to the age of the earth is obtained. From the age of the earth one steps back into astronomy, to the cooling down of stars and to other related phenomena.

Within the same Division is the Committee on Paleobotany, set up for the purpose of encouraging research in a borderland field in which as yet there are comparatively few workers but which holds great promise for enlarging our knowledge of the life of the past.

Many years ago Professor Lindgren while chairman of the Division of Geology and Geography made a study of the outstanding unsolved problems in the field of ore deposits. That investigation was published and for several years thereafter contributions appeared on the problems which he had outlined, notably among them the suggestion that experimental work be undertaken on producing replacement phenomena under artificially controlled conditions.

The Division of Biology and Agriculture has a Committee on Radiation which has made most fundamental contributions in a borderland field. The project was initially formulated by Dr. W. C. Curtis, who realized the great advances which had been made in the study of radiation in physics and the very important biological applications thereof. Some of the findings of this Committee on Radiation will be published in a forthcoming volume which it is hoped will stimulate further research in this field.

The Division of Physical Sciences in cooperation with the Division of Geology and Geography has for some time had a large Committee on the Physics of the Earth. The work of this committee is summarized in six volumes under the following titles: "Volcanology"; "The Figure of the Earth"; "Meteorology"; "The Age of the Earth"; "Oceanography," and "Seismology."

One of the major activities of the Division of Medical Sciences has been the work of the Committee on Drug Addiction, in which possibly as much as half of the work belongs in the field of chemistry as distinct from the other half, which comes in the fields of physiology and pharmacology. The work of this Committee emphasizes the fact that one of the greatest needs in biological chemistry at present is the induction into it of thoroughly trained organic chemists who are able to analyze and to synthesize the chemical entities so intimately concerned with the physiology of the human body. Further advances in this most important field await knowledge of the actual chemical structure of these substances and the development of methods for their synthesis.

In the Division of Engineering and Industrial Research there are extensive activities in borderland fields such as are represented by work on the international steam tables, fatigue phenomena in metals and marine piling investigations. Indeed, it is perhaps not too much to say that most if not all of the activities of the Division of Engineering are to a great extent representative of borderland problems, if by such problems one means those which involve elements covered by other divisions of the Council. The very fact that engineering, as well as medicine, is an applied science means that inevitably investigations therein must draw heavily upon the pure sciences and therefore must constitute in effect a borderland field.

OTHER RECOGNIZED BORDERLANDS

Geochemistry. The materials of the earth provide the starting point for the work of the chemist. The usefulness of chemistry to the geologist could perhaps be greatly increased through the perfection of rapid and relatively inexpensive methods of analyses that are roughly quantitative and applicable to small quantities of material. The well-established inorganic reactions of ordinary temperatures should be supplemented by experimentation with mixed solutions at elevated temperatures and pressures and in the presence of volatile components. Especially significant would be experiments with solutions analogous to those believed to be involved in ore deposits. The Geophysical Laboratory of Washington has carried on large amounts of chemical work of fundamental importance. The extension of these experiments to more complex systems closely imitating those occurring in nature might yield highly instructive results, even though their full explanation may not at the outset be clear. There is reason to believe that the solubility of silica is very greatly influenced by temperature and by the presence of certain salts in solution. Systematic work in this field should be undertaken.

The geologist is also keenly interested in the field of colloid chemistry. The study of ores is constantly revealing new evidence of transport and deposition of ore minerals in colloidal suspension. These are but a few of the numerous applications of chemistry to geological problems.

Bacteriology. Bacteria have played an important rôle in the formation of oil; and sulfate-reducing bacteria now living in soil waters associated with oil have notably modified their composition, converting sulfates to carbonates. The bacteriology of oil and oil-field waters should be the object of cooperative study between the biologist and the bacteriologist; that is to say, the soil bacteriologist rather than the medical bacteriologist.

Parenthetically, it seems probable that the study of classification of soils from the standpoint of fertility is a field to which the geologist could make important contributions. The problems of base exchange in soils are important to the agriculturist as well as to the

geologist and the ceramist in the origin of clays and in similar problems.

Geophysics. This subject has developed to the point of receiving recognition by the formal organizations of societies or laboratories such as the Geophysical Union and the Geophysical Laboratory of Washington. Among the major problems of geophysics are those relating to the earth's interior, its composition and the distribution of density, rigidity and temperature. The problem of equilibrium or isostatic adjustment between high- or low-line segments of the outer portions of the earth, and the problems of the mechanics of mountain-making have long demanded attention. Among other equally important problems of geophysics may be mentioned the problem of crystal growing; the physics of yielding mechanisms such as clays and sand.

Fatigue in Metals. This is a field of very great importance, involving not only various branches of chemistry and physics but engineering as well. In spite of many studies, a vast amount of work yet remains to be done, and it is probable that only a concentrated attack by the bringing together of a large number of specialists to collaborate in carrying out a well-organized plan can bring conclusive evidence to bear upon this wide field.

Photogrammetry. There is a rapidly growing literature in this field and there has recently been organized a Photogrammetric Society. The Fourth International Congress on Photogrammetry met in Paris in September, 1934. A limited number of methods have been employed in reducing aerial photographs to a plane surface. There are obviously involved in the solution of this problem both optics and mechanics as well as the distortion of the various materials employed, particularly photographic films, printing paper and the like. The American Geographical Society has for some three years been engaged in research on questions of improving existing techniques. Mathematics, physical and geometric optics, photography, psychology and chemistry all united in providing means for attacking this problem.

CONCLUSIONS

It will be agreed that borderland fields should receive some special stimulation, partly because of the inhibitions mentioned above; partly because of the fact that there are, in general, no scientific societies or journals to provide a common meeting ground for those who by chance become interested.

However, it will also be agreed that undue artificial stimulation, "by the gods on Olympus" deciding what should be done and setting other people to do it, is highly undesirable; and in the long run is likely to prove detrimental. In the fields of pure science at least, specific machinery directed toward the organization and prosecution of research has availed little. Original, enthusiastic, capable investigators are not attracted by such means. The whole history of science shows that progress rests in the main on individual initiative. It is this that must be encouraged, whether in borderlands or in the conventionally recognized subdivisions of science. In this respect promotion of research in borderland fields offers no unique problem. But how can we see to it that the individual is encouraged, and not discouraged?

Surely, no complete formula can be written. But the following suggestions are made:

(1) Steps should be taken to see that no worthy problem falls between two stools. Whenever there is presented a problem or a proposal that lies between two or more sciences, make it by special assignment the joint responsibility of competent representatives of the sciences concerned, so that the problem may be evaluated on its merits and receive suitable support.

(2) Whenever activity in a given borderland field seems to be generally developing, provision should be made under some auspices to stimulate interest by originating joint research committees representative of the fields involved.

(3) Scientific societies should be encouraged to continue to hold borderland symposia. The National Research Council would be glad to cooperate in planning these meetings.

(4) Universities should be encouraged to give special or regular courses in borderland fields; and to break down the water-tight compartments that all too frequently are found in academic circles.

(5) And in general steps should be taken to remove the inhibitions in the way of borderland fields so that they may, along with the recognized sciences, develop naturally and without regimentation.

SCIENTIFIC EVENTS

FEDERAL APPROPRIATIONS

AN Associated Press dispatch printed in *The New York Sun* reports that, according to an official accounting of approved work-relief projects, appropriations for highway and street construction work were calculated at $855,000,000. Other items in the summary of federal allotments for approved enterprises were:

Civilian Conservation Corps, $522,084,000.

School buildings, $174,243,000.

Other public buildings included in the Public Works