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THE NATURAL SCIENCES IN GENERAL EDUCATION: PRACTICES AND PROBLEMS

I. The Stimulus of General Education

In recent decades, many teachers of the natural sciences have contributed to, or have been influenced by, the movement toward educational reform known as general education. The result has been a proliferation of science courses, astonishing in their variety by comparison with the essential uniformity of the older modes of instruction in the sciences. In any one science, such as physics or chemistry, elementary instruction had become, and still is, quite conventional. Except for minor variations in emphasis and detail, one textbook can be exchanged for another and even laboratory equipment is standardized. A teacher in such a course may experiment with pedagogy, but the materials of the course are predetermined, and the end is preparation for further study in the field. The advent of general education has had an effect something like the opening of Pandora's box, except that the story should be altered in two important respects. Whereas, in the myth the myriad of creatures which were suddenly released from the box constituted the miseries and misfortunes of mankind. some of the new science courses point the way to significant improvements in scientific education. Secondly, Pandora's opening of the box was irrevocable, and there was no possible hope of recapturing the escaped evils, while, in the realm of education, we may still hope to coax back into the box some of less fortunate results of curricular experimentation. But this is an unduly harsh note. The opening of the box symbolizes the freeing of many teachers of science from certain conventionally accepted bonds, both institutional and intellectual. Many have been confronted, perhaps for the first time, with problems of ends, and with a wider range of means than those hitherto delegated to them. These problems are being discussed and acted on. The scientific part of the educational enterprise is being re-examined, along with the rest. One of the purposes of this paper is to characterize some of the results of this re-examination.

In order to do so, however, it is necessary to consider also the meanings which teachers of science have associated with the idea of general education itself, because it is in this context that the new courses have been evoked. In many instances, it is not discontent with scientific education as such that has generated change, but the influence of a more generic discontent with undergraduate education. More often than not, an administration or a faculty has decided that general education is the order of the day; subject matters are delegated to various committees, and curricular revision is on its way.

II. Breadth of Knowledge as a Principle

The early notion of general education, twenty or thirty years ago, derived its substance from the evils of specialized education, which it was designed to correct. Specialized education was narrow and incomplete; general education should be broad and complete. It should, in fact, be a survey of all knowledge. Its end was the orientation of the student in all fields. Knowledge was divided up into several parts, usually entitled humanities, social sciences, and natural sciences; and all of the departments of a university that would fit were assigned to one or another of these areas for the purpose of organizing a general course which would cover the area. Scientists found themselves in one of the large areas, but the boundaries were too remote for comfort, and it has been the almost universal practice to subdivide the natural sciences further into physical and biological sciences.

The principle of breadth, which suggested that all students study all of the principal areas of knowledge, suggested in turn, that they study all of the fields within the area of the sciences. In one form of survey course, petit courses in physics, chemistry, astronomy, geology, or in botany, zoology, physiology, embryology, etcetera, were strung together like beads on a wire. There were problems concerning the order and relative sizes of the beads, but within each subject matter, the great generalizations and fundamental theories were summarized and illustrated. From protozoa to man, from falling bodies to cosmic rays, the conclusions of science were arrayed in impressive sequence as the panorama of the biological and physical world unfolded. Specialists were called in to deal with their specialties. and were able to feel "at home" as long as petit physics and petit botany retained their identity. Also, these courses could be approved by specialists because they provided, as an audience, the whole undergraduate student body, instead of the smaller group planning to specialize in a given field. Breadth, in fact, was not necessarily an end in itself, but a means for more intelligent choice of a field of concentration.

What makes the survey course, with its coverage of vast areas of knowledge, conceivable, is a particular concept of pedagogy, namely, that narration can serve as the predominant mode of instruction. A one-year course presented primarily by lectures is assumed to cover the main ideas. principles, and conclusions that can be stated orally in about one-hundred hours. The lecture system is a reduction or assimilation of communication to the knowledge in the head of the lecturer. It assumes an isomorphism between the words of the speaker and the thoughts of his hearers, or perhaps a psychophysical parallelism between the minds of the one and the many. Even the emotions of the audience are said to be inevitable consequences of the lecturer's purpose, as when we hear that, "the students are surprised to learn that . . .," and so on. This is not to say that the lecture does not fulfill certain important functions in education, some of them uniquely. The exhibition of arts by the teacher is important. Nevertheless, the identification of narration and communication is one of the greatest bars to educational improvement because it effectively conceals from the narrator most of the symptoms of the failure of narration. While some of the characteristics of the early survey courses have undergone evolution, the lecture method, as the primary mode of instruction, is a widespread feature of the educational scene.

It is customary, at present, to disparage or disown the survey course, or at least, the word, survey. Some say the survey course has disappeared. There are good and sufficient grounds for criticizing it, although not, I think, for alleging it has disappeared. Nevertheless, it was, and is, a gust of fresh air through the overdivided rooms of the academic mansion. Combining the various physical or biological sciences, for example, in a single enterprise even if, at first, it was by mere addition, brought specialists together and provided an institutional framework for further thought and experimentation concerning the proper nature and ends of scientific education. Similar developments occurred in the social sciences and in the humanities. Now, the high walls around these larger divisions of knowledge need to be surmounted intellectually and institutionally so as to achieve greater coherence in the total educational process.

In the sciences and probably in the other fields, one of the earliest convictions was that it was desirable on pedagogical grounds for a teacher, whether trained in chemistry or geology or what not, to teach the entire course, and not just his specialty. This too has provided the opportunity for communication among specialists and the possibility of dealing rationally with the relationships and relative importance of subject matters which had hitherto been vested interests. But there are problems as well.

Whether Ortega[1] is right or not in saying that in politics and art, scientists adopt the attitude that there are no specialists in those matters, it is far from true that scientists have this attitude toward sciences other than their own. On the contrary, scientists and particularly teachers who have taught one science for many years, are reluctant to participate in general courses embracing many sciences. Nor are teachers particularly anxious to become learners for this purpose. Today, the survey course is regarded as an obsolescent first stage toward general education. Yet numerous colleges and at least one large university have refrained from taking this step in the sciences, due to the opposition of science teachers. A survey of 500 liberal arts colleges in 1948 revealed that 235 or 46% replied "No" to the question: "Do you offer a general education or survey type course?" The major obstacles mentioned were the opposition of departments and the difficulty of getting properly trained teachers. (Note, by the way, that "general education" and "survey type course" seem synonymous to the questioner).

III. An Historical Footnote

If the notions of general education as broad and complete are literally applied, as they were and still are, the result is superficiality, even to the point of absurdity. This is an interesting oscillation of the educational pendulum. It was fear of

[1] José Ortega y Gasset, *The Revolt of the Masses*, W. Norton & Company, New York, 1932, p. 124.

superficiality which led to the elective system. Added to this, the social need for experts produced the system of specialization against which the movement toward general education is a reaction. Historically, both movements, that of election-cum-specialization and that of general education are attempts to deal with the same problem, namely, the growth of knowledge in kind and amount beyond the possibility of detailed comprehension by any one person or in any finite educational experience. But breadth and consequent superficiality were, not for a moment, considered in the nineteenth century solution, following, as it did, in a tradition of mental discipline and intellectual mastery. In the words of a fervent apologist of that earlier educational ferment:

> (The elective system has become a general movement because of) the dread of flimsy study... The rise of physical science and the enlargement of humanistic interests oblige the college of today to teach elaborately many topics which formerly were not taught at all... Modern languages crept in, followed by sciences, political economy, new departments of history, literature, art, philosophy. For the most part, these were added to the studies already taught... To multiply subjects was soon found equivalent to cheapening knowledge. Where three subjects are studied in place of one, each is pushed only one-third as far. A crowded curriculum is a curriculum of superficialities, where men are forever occupied with alphabets and multiplication tables, elementary matters containing little mental nutriment. Thorough-going discipline, the acquisition of habits of intellectual mastery calls for acquaintance with knowledge in its higher ranges, and there is no way of reaching these remoter regions during the brief season of college life except by dividing the field and pressing along paths where personal friction is least.[2]

It was inconceivable, then, that the problem of the increase and diversification of knowledge should be solved by spreading education thinly over everything. The "acquisition of habits of intellectual mastery" was the goal, and this could be achieved only by "acquaintance with knowledge in its higher ranges."

[2] Geo. H. Palmer and Alice F. Palmer, *The Teacher: Essays and Addresses on Education*, Houghton Mifflin Company, New York, 1908, pp. 179-180.

The kind of knowledge, however, was irrelevant. The notion that a specified, common core of learning was the indispensable possession of educated men decayed as education began to be sought by a greater number of persons, from an ever increasing diversity of backgrounds, and with an ever increasing diversity of purposes. American society was becoming increasingly fractionated; knowledge was becoming increasingly fractionated; education, accordingly, followed suit.

The vacuum created by the belief that the content of knowledge was of no account was filled by the elevation of the act of choice to the rank of an educational principle. According to the writer quoted above:

> We say "Study Greek, German, history, or botany, — what you will: the one thing of consequence is that you should will to study something..." The will is honored as of prime consequence.[3]

IV. Neo-Survey Courses

The reversal of values has been quite complete. In many colleges, all students are required to take general courses, and few of these would claim to achieve intellectual mastery of the subjects included. On the other hand, none will admit superficiality as a necessary characteristic of breadth of coverage. The magic term which fends off superficiality as a consequence of coverage is *understanding*, and its opposite is *information*, *or* facts. The coverage of many, unrelated facts is admittedly of little or no educational significance, but the coverage of broad principles or central ideas, even when there are a great many of them, is said to lead to understanding.

Nevertheless, the emphasis on understanding as opposed to information has led, in many cases, to a search for relation-

[3] *Ibid.*, p. 182.

ships among the conclusions of diverse sciences, and to a reorganization of the materials previously embedded in their respective subject matter cubicles. The search for relationships within a broad area such as the physical or biological sciences has led in turn, to a second species of survey course, although this name would be disclaimed. Here it is meant to signify that large bodies of material are treated extensively, as before, although the rubrics have altered.

One such type of course depends on the epistemological principle that knowledge is unified, or should be unified for the purposes of a liberal education. In particular, it may be believed that science is a unity, and that this should be demonstrated by exhibiting as many different sorts of phenomena as possible under a single idea or set of ideas. Heat, sound, and light are treated consecutively as forms of energy: electrons, atoms, the earth, the solar system, and galaxies, as forms or organizations of matter; chemical reactions and geological processes as interactions of matter and energy. It was disappointing to discover, in one case, that these rubrics, matter and energy, were not extended to biological phenomena, to which they are obviously applicable; instead, the rubrics, protoplasm, reproduction, organism, and evolution, made their appearance. An opportunity to unify the physical and biological sciences has been lost! The moral is that unification, which proceeds by ignoring differentia, is indistinguishable from ignorance. There is an anecdote about a canny professor of mathematics who claimed that he could comprehend all knowledge in a single letter. When challenged, he replied: "Let the letter *K* stand for all knowledge."

Another type of survey course finds its coherence in the principle that the physical world is a unit. Thus, material from various fields can be integrated. "For example," as the professor in one such course states, "the discussion of the stars has scarcely begun, before the telescope is mentioned." (An integration of physics and astronomy). This course begins with a consideration of the whole material universe as seen in the study of the stars, then magnifies the sky, with a telescope of course. For a closer look, attention is focussed on the sun. Eventually, the earth is approached from the outside, throught its atmosphere, and subsequently, its interior is penetrated with a study of vulcanism and diastrophism. When the course gets to the center of the earth, it turns to number systems and logarithms in preparation for a study of atoms and molecules, which exist in large numbers. Other courses of this sort turn the universe inside out, so to speak, and start with electrons and atoms, proceeding by stages to stars and galaxies.

Still another type of survey course, in the hands of persons trained in the history of science, employs chronology as its organizing theme, as might be expected. Unlike the previous courses, which go from the large to the small, or from the small to the large, surveys of the history of science go from the beginning to the end. Cultural, social, philosophical, and other strands may be woven in to the account of the succession of scientific discoveries. There may be no clear distinction between science as a social phenomenon, as a humanistic achievement, and as verifiable knowledge of the external world, to the detriment of all three aspects, and especially the last. If the surveys of scientific conclusions are prone to superficiality, surveys of the history of science are triply liable to the same error.

These courses are all identifiable as courses for general education on account of their breadth and the absence of any definite relation to further, specialized work in a particular field. They have, in addition, the common characteristic of preoccupation with scientific method. Practically all survey courses deal with method as one of their numerous topics, either because the student should learn to use the method in daily life, or because knowledge of method is part of understanding science. Hence, one or a few lectures are devoted to method. It is unnecessary to comment in detail on the disparity between the means employed and the end sought. The problem of scientific method is, to a great extent, an unexamined one among teachers of science. It may be hoped that the continued inclusion of insight into method as one of the goals of scientific education will stimulate teachers to investigate, on the one hand, systematic philosophical positions on method, and, on the other hand, the actual scientific inquiries to which those positions are said to be applicable. Until the education of scientists and of teachers of science undergoes radical change in the direction of appropriate historical and philosophical study, self-education and, above all, communication among teachers, must be relied on the correct naiveté and dogmatism concerning scientific methodolgy.

The superficiality of the neo-survey, with its arbitrary choice of abstract themes, and its disjointed treatment of method has, in a few instances, produced its own reaction, on pedagogical or philosophical grounds, or both. A few staffs have organized instruction around the concept of the *problem,* that is, around the notion that an inquiry, a question or a set of related questions, is the proper nucleus for the congerie of interrelated data, methods, and conclusions that constitute a segment of scientific knowledge. The demands of intellectual mastery can here be satisfied in a limited area. A kind of completeness is discovered in the specifiable adequacy of a given conclusion to its generating problem, and the completeness of broad coverage is abandoned. A relatively small set of problems is chosen with an eye to variety in subject matter and method. In one case, the problems are allegedly chosen, also, on account of their intrinsic interest to the student, and are formulated as if they were the products of curiosity alone. Not "What is the nature of the atmosphere, and how can its properties be accounted for in terms of knowledge of the gaseous state, etcetera?" but "Why does the air grow cooler with increasing altitude?" Nevertheless, it is obvious that the questions are chosen with an eye on systematic bodies of knowledge close at hand. In other courses, the problems raised are admittedly those raised and pursued by scientists, generated not by curiosity alone, but by the desire for greater consistency, or generality, or precision, or all of these. These two approaches, however, are or should be, opposite faces of the same coin. Random questions, outside the context of what is already known, seldom lead to an extension of knowledge, however interesting the questions may be. Conversely, scientifically fruitful questions will fail pedagogically unless they are interesting to the student. The ideal solution of the problem of motivation occurs when the student becomes interested, in the first place, in the abiding scientific questions, and learns to ask his own questions in the context of knowledge.

V. Problems

As the foregoing narrative has implied from time to time, there are problems involved in the extension and improvement of scientific education. These relate to personnel, to pedagogy, to educational organization, and of course, to theory.

The problem of teaching personnel in the sciences, difficult as it is, is complicated by the increasing rift between the teaching and research functions. Now that government and industry possess elaborate research organizations, and subsidize still other extensive research programs within universities, young men trained in science need no longer combine teaching and research in what used to be regarded as the ideal academic career. There has been a serious improverishment of the pool of competent and well trained persons who might be, or become, interested in educational problems. Even without this social problem, the difficulties are great enough. As scientific instruction in the framework of general education evolves away from traditional modes of instruction in both form and content, especially as scientific problems are taught in philosophical and historical modes, and as traditional training persists unchanged, a number of problems ensue. First, the disparity grows between the knowledge, skills, and attitudes desired and available in teachers of courses of the newer sort. This is not an overriding difficulty where the staffs of such courses possess an experienced nucleus, but this is by no means a typical situation. In a great many institutions, the challenge of general education has not yet been met. The need is for teachers who will break ground where it has not been disturbed for many years. Even where there is administrative encouragement, a teacher, or group of teachers, attempting new methods and materials, must contend, not only with the deficiencies of his own education, but also with external resistance and misunderstanding. Within institutions, there is frequently tension between those engaged in general education, and those engaged in specialized education in the sciences, on account of theoretical differences and also because of the disarticulation of the general and special parts of the curriculum. In a few universities, faculties of general studies have been detached and given autonomy, thus permitting freedom of experimentation, but however worthy, this radical solution is frowned on by most institutions, nor has this device alleviated the tensions described above. Finally, academic personnel engaged in general education in a university are harassed by the double standard of compensation and promotion for teaching on the one hand, and research or publication on the other, especially since the new education requires thought and attention far beyond the call of duty of the usual, elementary specialized courses. In the liberal arts colleges and in the autonomous general studies faculties, this problem has been minimized, but even here, it may exist because of the echoes of academic mores outside.

Closely related to the problem of personnel is one of pedagogy. Courses prescribed for all students in a college have to deal with very large groups of students. Yet, the available personnel is limited. The lecture method is the only possible mode of instruction with limited personnel, and it was widely adopted along with general education courses of one sort or another, even where it had not previously been employed for specialized courses. In some quarters, the unique advantage of the lecture system as a means of exhibiting distinguished professors to multitudes of students is cited. So is the low cost of this system. Nevertheless, a great many teachers are convinced that one-way communication can never produce the habits and skills of critical analysis so frequently mentioned as goals of general education. A few colleges and universities, to their great credit, have undertaken the considerable cost and the personnel search required to teach large bodies of students in small discussion groups. Even the best intentions, however, will not produce competent personnel quickly, and, in the sciences, there is the ever-present competition of the research career.

A third problem involved in the reorientation of undergraduate education is the ambiguity and confusion in the relationship between the curriculum of the secondary school and that of the college. It goes without saying that if one function of the secondary schools is preparation for college, and if colleges re-examine their goals and reorganize their curricula, confusion ensues. But part of the confusion is due, also, to the fact that some secondary schools re-examined *their* goals and curricula and did so in the name of general education. The high schools of the twentieth century have had to face the fact that the great majority of their graduates do not go on to college, and must therefore, (quote) "be prepared for life." Preparation for life has, for the most part, taken the form of vocational courses of study (or should one say courses of practice), which exist along side of the college preparatory course, quite distinct from it and somewhat less respectable. The latter has been a well-defined collection of units in English, foreign languages, mathematics. sciences, and history, each of which is a recognizable antecedent of further work in English, foreign languages, mathematics, sciences, and history. Both high school and the college knew where the other stood. The movement toward general education threatens to change all this. If general education is desirable for everyone whether or not he goes on to specialized work, if, in other words, general education is preparation for life, educators have reasoned, then the high schools should be doing it, and presumably for all students. As it happens, the secondary schools and the colleges view the problem from rather different points of reference. Discussion of secondary school curricula tends to center around educational psychology and philosophy; it speaks of the current needs of the adolescent, and explores scientific knowledge for possible contributions to consumer know-how, sex education, democratic values, and reflective thinking. The collegiate endeavors have tended, on the other hand, to expand outward from scientific knowledge itself as a center, speaking of the understanding of science and of the role of science in society as goals. Nevertheless, both approaches are attempts to deal with the common problem of life in the complex society of today, and no sharp distinction may be drawn between education at these two levels. Adolescents in the last year of high school are likely still to be adolescents in the first year of college. and conversely, the rigor and internal logic of knowledge as such may be of value even in the general education of younger students. Aside from questions of theory, this situation poses questions of educational organization. Should a single unit or school be set up to engage coherently in the kind of education which everybody should have. with a single faculty and a central purpose, in which the problems of the nature of knowledge, of the student, and of society can be brought to bear on one another? Is the present division between secondary school and college a meaningful one if both engage in general education? A number of universities are, at present, encouraging the admission of able students who have not yet graduated from high school as a way of extending a coherent educational scheme to a younger age group. That this can be done successfully is amply proven by a decade of experience with younger students on the part of one of these universities.

If however the present school units retain their identity, and if, as seems commonly agreed, the years for general education overlap school and college. what should the division of labor be? The University of Puerto Rico and the model high school closely associated with it now have the opportunity of exploring this question. As I understand the proposal, three-year sequences in the physical sciences and in the biological sciences are to replace the present courses in physics, chemistry, and biology in the high school. There will, likewise, be a three-year sequence in mathematics. If these sequences are successful and are adopted by the other high schools of the Island, then the one-year programs in physical sciences and biological sciences in the University can become the capstones of a four-year general program in the sciences. Preparatory and high schools on the Continent are thinking in the same terms. A recently published report by members of the faculties of Andover, Exeter, Laurenceville, and Harvard, Princeton, and Yale speaks of reshaping the last two years of high school and the first two years of college into a unified, consecutive, educational process.

So far as the sciences are concerned, a program of the duration and extent proposed for the University High School here can readily solve some of the problems which bedevil shorter courses. One of these is the problem of achieving breadth without superficiality. Scientific knowledge is cumulative and synthesizing, but neither the nature nor the power of synthesis can be exhibited without considering the disparate phenomena which are synthesized, and their differentia. It is the differentia, after all, which create the problem for which synthesis is the solution. The study in detail of a variety of manifestations later to be subsumed under a single idea is therefore important, and this takes time. The great temptation, which is succumbed to, practically always, in secondary school textbooks and courses, is to leap from phenomena to relatively high order abstractions. Evaporation. for example, is at once explained in terms of molecules, chemical reactions in terms of the periodic chart, the pendulum in terms of energy transfer, and so on. As a result, the abstractions may be remembered but are not understood, and more important, the phenomena are circumscribed by the abstract ideas which bind them to other phenomena. They become pale images of an idea. Sodium metal, for example, loses its reality as a substance and becomes a place in the periodic table of the elements. It is possible to conceive a course for younger students which proceeds by slow inductive stages from congeries of phenomena thoroughly investigated and explained in low level descriptive terms to more abstract concepts. The fruit of this procedure might be students who have not only heard that the moon moves around the earth but know where and when to look for the moon. This is not a plea for natural history without intellectual content as a function of beginning instruction. On the contrary, an extended course should permit a thorough exploitation of the web of facts and ideas involved in even the simplest observations.

Another advantage of a sufficiently lengthy program in the sciences is that eventually it can arrive at more recent concepts without hazard to the understanding. Almost without exception. recent discoveries, in nuclear physics and cosmology, for example. are presented in a manner that is admitted to be superficial even by those whose entire approach is here criticized as superficial. It is said that these matters must be mentioned least students be frustrated or disappointed by not hearing the academic blessing bestowed on what is described in the newspaper headlines. This is the *reduct ad absurdum* of scientific education, but it does illustrate the dilemma of too much knowledge and too little time. Students should feel frustrated, not because of the absence of certain topics, but because of the absence of evidence and argument, and therefore of meaning and clarity. The habit of demanding illustration and argument appropriate to a subject matter requires time to develop, and so it is with all habits and skills. This, then, is a third advantage of an extended and coherent curriculum. In short, unless the secondary school makes a genuine and sustained contribution to the general education of the student, the efforts of the college prior to specialization are too little and too late.