Relationship of Biology and the Other Sciences in Teaching

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It has often been stated that a new breed of educated laymen and general scientists is needed to provide leadership in a world where at every turn the factual aspects of science are affecting the decisions of society. Furthermore if democracy as we have known it is to survive, every citizen must know enough of the detail of science to judge the large issues facing the electorate. Whether it is medicine, atomic energy, world resources, military research developments, conservation, or long range planning of public initiative programs, detailed scientific questions are now involved. If the scientists are too narrow to have perspective on the general issues and if the laymen and their non-scientific leaders are too nonconversant, then God help us. Who is there left to lead? The only real hope is in education, not for more specialists but for more general scientists both among the citizens and among the scientists.

It is perhaps presumptuous for any man to agree to talk on this title "The Relationship of the Sciences in Teaching," but we have been drawn into the science curriculum discussions because of our efforts to set up at the graduate level an interscience minor in Marine Science at The University of Texas Institute of Marine Science. We are trying to set up on a very small scale a kind of graduate minor curriculum that can be a model for higher education everywhere. According to the ideal, science majors including those planning for secondary education are required to become grounded in all the sciences and learn and apply basic principles of physics, meteorology, earth science, chemistry, botany, zoology, and microbiology to an extent that permits them to coordinate and apply their knowledge to the understanding of the sea. No division is made between fresh waters and saltwaters for the principles are similar and the inland lakes serve as small experimental oceans and as laboratories for research and teaching inland. Although the details of the minor program are far from proved, the concept of a broad science organized and held together by focus on the environment has become established in the marine science institutions for some years. For example, the American Society of Limnology and Oceanography was founded on the interscience ideal. Its publications and meetings truly have no science boundaries. Far from being superficial, the levels of knowledge required to understand the sea are most respectable. The minor program, therefore, is one way to develop leaders trained in science but not so narrow as to be illiterate outside of their specialty. So much for general science at the graduate level.

But what of our greater responsibility in creating the general scientist in the citizen? What is needed in the high school science curricula? Let us review a dilemma in high school science.

Over the past twenty years the universities and colleges by providing strong introductory science courses have without knowing it undermined and wrecked the possibilities of science curricula in the high schools. In other subjects like English, mathematics, and history, the university and the secondary school have a firm agreement as to what is to be covered thoroughly and what achievements are necessary before the student leaves high school for college. There is a definite step sequence of accomplishment, a necessary body of detail covered and mileposts of student preparation for the next steps. The university thus expects the freshman to have certain accomplishments and does not ordinarily duplicate the high school in mathematics, English, and history except in those places where effective education has collapsed.

In the sciences on the other hand in comparison to the aforementioned subjects, there is chaos. By establishing strong general chemistry courses, general biology, or general earth science courses with no assumed knowledge from the high school, the college has taken the prerogative away from the high school. We are not now interested in the understandable history. We must look now forward to see what the high school can do under the circumstances. If a high school puts in a strong biology or chemistry course, the student finds himself having to repeat in college—a deadening and duplicative waste although he may gain background. If the school takes the other alternative and eliminates the detailed science, then he forfeits the responsibility to the non-college student, and also fails to give the student any background or motivation for the later work. Under the circumstances the high schools have often done a rather good job in compromising, giving some science for background purposes, but not usually duplicating the strong college courses. But the situation is not considered satisfactory if we are to judge by the general feelings such as those which led to this Conference.

What then can the secondary school teach that will make general acquaintance with science for the citizen and at the same time prepare half of them for most efficient transition to college? In other words what will help both the college curriculum and the aims of general education? Is there any different approach?

The suggestion is to greatly strengthen the general sciences concept in high school (Not general science but general scien*ces*). This should not be a miscellaneous bunch of facts picked as easy enough for teachers without preparation, nor should it survey. Nor should it necessarily be taught at the freshman high school level. It should teach a few things and teach them well—especially difficult, intellectually challenging things. The following are seven aspects of the course or courses.

I. It must be organized about the *great scientific* issues of our time, not only those affecting the public life, but those with the greatest intellectual challenge. Each issue must include with it all the necessary details for understanding. The following are some of the issues in the life sciences which inherently involve other sciences.

A. The *fundamental living machinery* in all kinds of cells and tissues in microbes, elephants, trees and in all the manifestations of life is very similar in basic workings. The general chemical cycles in the machinery are readily taught in broad outline. The temporary storage of energy in high energy compounds is used for many different purposes, nerve transmission, eye photochemistry, muscle contraction, electric eel shocks, cancer. The old story from the early 19th century in the generality of protoplasm has been verified in brilliant discoveries of the past two decades. In learning to control the basic machinery or adapt it, what possibilities are there in man's control of life? Some details need to be presented to all citizens.

B. The *energy laws* of general physics find vivid meaning in the living organism. The food and chemical energy going into living systems is degraded within into less useful form as prescribed by the second law of thermodynamics. A small part of the energy is retained and stored as new growth, but each increase in organization must be accompanied by dispersal of a great amount of organized food energy into heat. The unique powers of all life, man being no exception, may be explained because the living organisms burn great quantities of chemical energy at steady rates. The implications for the future of life and its dependence on energy sources is a magnificent subject that may be related to man's survival, past and future. These may be the most important laws of all science for man's next few decades.

C. The *process of photosynthesis,* the nature of chlorophyll, the factors regulating the living photochemistry, the day and night cycles, the chains of chemical events, the effects of light, the seasonal and latitudinal possibilities, and the efficiencies of utilization in laboratories and nature are all aspects of the most important single step in man's food chain. The general failure of modern research to increase total photosynthesis over that conducted by nature in forests and other environments is a major point for man's future. The possibilities of photosynthesis in chemical industry without living cells is a tremendous idea in the present press of scientific research.

D. The great *issue of evolution,* its proved and unproved facets, the parts which are still so much in mystery, the beautiful designs of modern speciation in all parts of the world, the solid facts of the fossil record, the scale of complexity of the nervous systems, the many ideas of the origin of life, the presence and absence of proofs, and the dogma of both the mechanist and the vitalist must be brought gently but firmly to the citizen regardless of the now outdated customs for noncontroversiality in high school biology. How else can one show better the difference between belief and evidence than in evolution where there is some evidence as well as some belief? It is here that the consideration of many kinds of animals belongs. If evolution is left out, one has potentially dull categorizing of creatures remaining.

E. The nature of *radiations and their effect on protoplasm,* nucleic acids as the fourth major category of important organic compounds in living systems, the nucleic acid nature of chromosomes, the localization of genic action in the chromosome, and the mutations with and without radiation provide an exciting story related to modern spread of atomic energy in the life of the civilization. The behavior of radioactive atoms in fall-out in being taken up and concentrated by living organisms may well wake up the most dormant minds. The other effects of radiation on the blood systems of the whole mammal, on cancer, on survival, and on subsequent generations must be inherently fascinating to any individual who can find motivation for the depth of work necessary to understand what is known of radioactivity and life.

F. The workings of single nerve cells and the *interworkings of all the neurons to operate as brains* must seem real to all students. The action of drugs and damage experiments in controlling the will and actions of the nervous system must be brought out. There is no better place to hear the opposing points of view of mechanism and nonmechanism as in the personality of a living system. Without attempting an answer where there is none, the classes may find strength in themselves by understanding of the mechanistic parts of the nervous system.

G. The ideas of *population genetics* may be developed in animal examples and forthrightly discussed relative to *man's future*. The selection of greater and greater numbers of individuals that formerly did not survive, must suggest the long range effect of medical science that must make necessary an ever increasing percentage of cost for survival through medicine. What happens if medicine is suddenly discontinued? Such issues must seem vital to youth.

H. A possible breakthrough may come in controlling the *differentiation of cells*. How do cells go through steps to eventually specialize as muscle, blood, bone, fiber or *cancer* cells? Why can the salamander regenerate its legs from a bunch of plain cells, whereas the frog-like man cannot? If regeneration can be manipulated, what hopes are there for treatment?

These great issues are but samples. There are many more: the cycles of trace elements and the meaning in terms of scarcity of critical raw materials for plant growth and civilization; the great idea of metabolism and size and the possibilities of controlling the tremendous metabolic power of small microorganisms both in nature and in industry; the idea of order and pattern in the growth and succession of natural forests and the possibilities for managing nature at low cost.

The teacher will find many great issues well stated in *Scientific American*, *Scientific Monthly* and the British magazine *Endeavour*. Usually, these presentations are superficial and some additional detail must be obtained from advanced textbooks if understanding is attempted. Some reference source book is needed for the specific purpose of providing the high school teacher material on the great scientific issues and the detail for understanding.

II. *Every science* must be represented so that the student when he completes high school knows what sciences there are, what their philosophical approaches are, and has enough detailed background so that he can elect a sensible freshman science curriculum in college. Too often a freshman unaware of the importance to his future relies on an overworked freshman advisor and the absurd contact of 5 minutes for choosing the directive influences for his lifetime.

III. In each science the *basic principles* are to be presented without abbreviation or watering down even though mathematical formulation of some kind is involved. For example in physics, some main laws of mechanics, light radiation, heat and earth physics must be covered. In biology simple biochemistry and genetics is not to be omitted, but the science should not so cover the cream of details that the college courses don't seem like fresh experience. Many present texts are too full of miscellaneous facts about the result of science or its applications. Leave out of the textbooks the pleasant pictures of smiling boys and girls doing things. Teach science, but don't talk about science.

IV. There must be a *controlled experiment* performed by each student on some issue that he chooses and for which no one knows the answer, not even the teacher. The class then should discuss an interpret the results and suggest further experiments. The students should give his results to the class orally and in written report. At least 3 weeks is needed to do this thing thoroughly. The general concept of replications and validity of duplication must be emphasized and the idea of authoritarianism of the teacher or textbook abolished by such process. Imagination in designing experiments can be stressed.

Although interested in science since the 7th grade I performed the first experiment for which I did not know the answer in the second year of graduate school, yet in every grade *ad nauseum* we heard how *The* Scientific method is done. If we didn't get it right on the test, we were penalized by the authority based on textbooks by persons who had never done any experiments. Don't mistake the experimental suggestion for the usual science fair stuff where something is constructed or some advanced science apparatus is built. Science fairs have part of science, but they lack another part of the basic flavor. Science is a way of working with the unknown, whereas the science fair is sometimes a pat on the back for precociousness in knowledge or fabrication rather than a development of the attitude and approach of the experiment. In the 3 weeks experiment suggested, for example, a student might test the effect of local stream water on tadpoles to see if there was toxicity present. He would set up ten bottles, as control, and several groups of ten bottles each with various concentrations of his unknown water. No great detailed knowledge is required of a teacher stimulating and supervising such experiments, because his or her contribution is to show the ways of thinking, attitudes of suspicion about alternative theories, criteria of proof, and ways of getting results.

V. The sciences must be considered in their proper order. The time has now passed when the life sciences can be understood or approached in any thing but a farcical manner without some simple physics and chemistry being taught first. Most of the great ideas and generalizations of the past two decades cannot really be understood until some simple knowledge of chemical elements, covalent molecules, reactions, and energy laws are learned. Yet many schools are still trying to give a mixture of superficial biological facts before teaching some chemistry and physics. There is little excuse for this now, because many good college texts have satisfactory introductions with basic chemical and physical laws and details as are needed to understand metabolism, high energy compounds, growth. Thus some basic physics, some chemistry, and then afterwards, the biology should be taught. These subjects should be labeled at the time so that the students get some concept of the divisions of knowledge. The best interscience training comes from identifying the various sciences and learning the premises and laws of each, not in coalescing them and losing the patterns of present organization. Put it all in one course if you like in order to make sure it is covered. Needless to say new books will be needed and both high school and college authors must be involved if the gap in planning is to be healed.

VI. In the *laboratory* in addition to the 3 weeks on a controlled experiment of unknown result, focus all the sciences on a unifying objective. Do not try to repeat the detailed kinds of apparatus experiments and microscopical work that colleges have now so firmly established. Even if it were desirable, the cost to the educational structure could hardly be justified and never as a duplication. If we were starting from scratch our recommendations might be different, but we are faced with an established situation.

One suggestion for at least one semester of the general sciences course is to follow the flow of energy from space into a small pond on earth. The actual pond can be no more than a pool or even a series of tanks built for the purpose outside. Concepts of astronomy, radiation, photochemistry, photosynthesis, food chains, populations, metabolism, microbiology, geochemistry, and many others can be included. Students may use inexpensive light meters, carry out growth and metabolism experiments, run bacterial plates, do some simple colorimetric chemistry, make counts, etc. The important aspect of many attacks on one pond provides application and unity.

VII. No such course should be attempted unless it can be set up in some kind of *agreement with the colleges* so that everyone can come to a realization as to what high school science is going to cover and what the colleges can assume. This probably can be accomplished by the simple medium of making some satisfactory textbooks with great issues available. If something like the above course is operating the college would expect the students to know what the main sciences are and several of their basic laws, what the great scientific issues are now, what an experiment in the unknown is from real experience, what interaction there is in a spot of the earth between the various sciences based on unifying principle of energy flow, and what scientific issues must be solved if mankind is to survive. What the college would *not* expect from the high school by this plan would be: any large duplication of the great massive detail now taught in strong college courses, any one-sided treatment of science, or any great experience with apparatus.

On the negative side, one should warn that there is no certainty that any attempt at general science along these lines will be any more successful than in cases in the past. Since no teacher is likely to feel strong in all fields of science, it may be difficult without special instruction. At all costs, a superficial, wordy, listing and naming of things and subjects is to be avoided. There must be definite laws, use of math, principles, problems, and plenty of detail given, but only that detail which is necessary to understand the big themes. Anything taught must be thorough and cleared with the colleges to prevent duplications. I have some misgivings about suggesting such definite curricula, but the dilemma is most serious. Public movements are pressing for more science in high schools yet under the present college system only inefficient duplication can result. Even students destined as specialists may very well be driven out of sciences by too much attempted in high school that serves only to undermine the college courses.

As a closing point about the great issues in general sciences course, we might suggest the issue of Jeffersonian Democracy based on sunbeams. The declining availability of cheap fossil fuels promises that man's civilization as we now know it may be a vanishing flash in the pan just like the dinosaurs or the trilobites. The way that all our advances are really based upon supplementing manpower with fossil fuel energy should be presented. Even our potatoes are now mostly from fossil fuel rather than from sunlight energy, since the great efficiency of our agriculture comes from the power used in mechanized farming, in running the agricultural experimental stations, and in the industries of chemical weeding. The symptoms of power decline are already appearing: more and more dryholes in the oil industry, competition with foreign oil, the steady rise of the cost of living and the struggle of nations for the Middle East reserves.

Two possibilities are possible as the fuel culture begins to decline. Atomic energy activities now based on colossal fuels expenditure may make the grade as a replacement in a few short years remaining. If atomic energy does not become practical, and it is not too hopeful because of the cost of disposing of lethal wastes, then we must fall back on the original basis of sunbeams. It is not really so fearsome to visualize the Jeffersonian Democracy although the 90% occupation in agriculture would be back with us. The important challenge may be in the planning now, in deciding how to maintain the best of our culture so that the new day will be qualitatively rich even though quantitatively we must be based on the energy levels of the 19th century. How to deorganize without crash and how to readapt may be for the present rising generation. Why not consider the possibilities, expand the vision of the youngsters, vitalize the details of science in our very survival, andtranscend the nonsense of adolescent culture into which youth are forced for lack of an early introduction into the main stream. Our admiration must go to those of you who will tell the stories that may yet bring man up from the fires of eternity.