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The Teaching of Biology

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hand with other organizations, including those that formerly were part of it but which had since withdrawn from it, in order to form a united front which eventually became known as the KMP. For certain reasons which we need not dwell at this time, the PTUC and several groups later on broke away from the KMP. It is wrong to say that the KMP owes its origin to the ICFTU influence. If there is any such influence, it was only because the PTUC, which was one of the prime movers for the organization of the KMP, was then—and still is—the national trade union center in the Philippines which is recognized by the ICFTU.

We make this correction in our interest that the Carroll article, which was excellently written, would conform more to the truth.

JOSE J. HERNANDEZ

The Teaching of Biology

In the history of Biology, beginning with the eighteenth century, there has been a strong tendency or direction of investigation from higher to lower levels of organization. This reductionistic or atomistic approach probably began with Cuvier and his detailed comparative analysis of organs. Bichat carried the process a step further when he classified human tissues. Schleiden and Schwann are generally credited with the statement that all organisms consist of cells, although Lamarck, Dutrochet and other biologists had actually stated this concept, the cell theory or principle, several years earlier. The cell theory established the cell as the ultimate unit of life. And in all plant and animal cells there is a complex substance, first recognized as living by Dujardin and first called protoplasm by Purkinje.

But this was not to be the end of elementalizing in biology. Now the cellular physiologist began to study the physical and chemical properties of protoplasm. He discovered that living cells are composed of the self-same chemical elements as are found in non-living things. However only a few of the existing elements have been found in living matter, the most abundant ones: carbon, hydrogen, oxygen and nitrogen. These elements along with a few less abundant ones exist in the form of compounds of great complexity—carbohydrates, lipids, proteins, hormones, vitamins, and enzymes.

Today there is great emphasis and progress in molecular biology. The structure of certain large molecules found in cells have been studied as well as the role of DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) in protein synthesis, the kinetics of enzyme activity, and the details of cellular structure as revealed by the electron microscope. Most of this current research in cellular and molecular biology is in the hands of biochemists and biophysicists, whose answers to biological problems tend more and more to be in physical and chemical terms. Ultimately these investigators are not dealing with an organism at all, but with a chemical reaction in a test tube or some form of physical model.

Fresco and Straus, biochemists of the Frick Chemical Laboratory of Princeton University, have recently stated: "Nucleic acids are currently a major focus of investigation for the modern biologist. This is because it is now recognized that nucleic acids are the master molecules of living systems: these macromolecules play a role in the hereditary process and in the dissemination of genetic information within a single generation. Among the great achievements of modern science has been the elucidation of discrete chemical steps involved in these processes. It has been found that the nature of hereditary information is the sequence of monomeric units (adenine, cystosine, guanine, and uracil) in deoxyribonucleic acids (DNA) and that these sequences are related to the sequences of amino acids in proteins. The chemical structure of DNA has also been shown to account for the self-duplicating character of genes. The expression of genetic information, as proteins of specific structure and function, involves its direct transmission from DNA to a type of ribonucleic acid molecule (RNA) whose own sequence of nucleotides is deciphered at the site of protein synthesis with the intervention of other types of RNA. Direct correspondence between nucleotide sequences in RNA and amino acid sequences in proteins has now been determined."

All of these past and present investigations have been essential and fruitful in giving us a better understanding of the function and development of the living cell. Yet in its extreme form pure reductionism offers no adequate explanations and permits no sound predictions of the behavior of the organism as a whole. As Simpson has said so well, "the action of an atom, a DNA molecule, an enzyme can be neither explained, nor predicted outside of the context of the system in which it occurs." This statement is a re-echoing of the organismic hypothesis that the activity or behavior of an organism is not the sum of the actions or functions of its separate parts, but that as a dynamic whole it transcends in behavior these parts. In other words the whole is not functionally the sum of its parts.

Grobstein, a developmental biologist at Stanford University, has commented that "isolation of biological phenomenon is essential—and yet dangerous. While it simplifies and clarifies the components obscured in the complexities of the higher order, it frequently drastically alters the behavior of these components and thus requires extreme caution in extrapolating back to the undisturbed system. On the one hand, modifications induced in components by isolation—properly interpreted—can illuminate the nature of the regulatory mechanisms of the whole system; on the other hand some knowledge and control of these mechanisms frequently is necessary to preserve in isolated components their most interesting and crucial behavior for comprehending the properties of the whole. Biological investigation thus involves a continuing cross-feed of information between analyses proceeding at several levels." Grobstein thus stresses the importance of a multi-leveled analysis and approach in biological research, i.e. a simultaneous consideration of molecular, cellular, and super-cellular levels.

This multi-leveled research approach is perhaps the key to the proper training and education of the biologists of the future. Such an approach requires a familiarity with and competence not only in the new knowledge of molecular biology, but also an equal excellence in the older knowledge, for multi-leveled research demands a multi-leveled training. The general aim of biology is to understand the structure, function, history, and populations of organisms. In its broadest sense it includes the study of all facts relating to living organisms, although some authorities limit it to those principles common to plants and animals. Biology also requires a certain familiarity with other sciences such as mathematics, physics, and chemistry.

The older knowledge, which for many years has been the undergraduate curriculum for pre-medical students and biology majors, is a study of organisms as individuals and in group relations. The former study is usually subdivided into morphology (anatomy, histology, cytology), physiology, and embryology. Morphology represents a static viewpoint; physiology a kinetic consideration, and embryology is both kinetic and static in approach. The study of organisms in group relation is subdivided into taxonomy, ecology, biogeography, genetics, and evolution. When these courses are taught on the undergraduate level they are usually presented in more or less air-tight compartments and in about the same order as they emerged in the history of biology.

For some time now I have been considering how we should graft the newer biological knowledge to the traditional course of the college curriculum. Should we eliminate some aspects of the older knowledge to make room for the new? Should molecular biology be presented at the beginning, middle, or end of the four-year course? How should we select and order the matter to give a new approach to the undergraduate course? What constitutes a well balanced program of studies for the training of biologists of the future? How can we best impart to our students the mentality and concept of multi-leveled analysis of biological problems? These are not idle questions and no quick and ready answers can be given.

In formulating a new biological curriculum there is a temptation to put the primary focus of attention on what is new. Ring out the old, ring in the new! Such an approach would fail to fulfill the general aim and goal of biology which is a study of organisms at all levels of organization not just the cellular and intracellular level. Someone has well said that modern physical and chemical research on organisms has no biological significance unless it is related to whole organisms and populations of organisms. In an article entitled "Levels and Ontogeny" Clifford Grobstein has some sober remarks to make about the future education of biologists: "Curricula devoted exclusively to molecular biology proudly bear the name of modernity, but the emblem is a shrunken and distorted caricature of the full range of biological phenomena. On the other hand, curriculum-design dominated by fear that safe traditional moorings may be swept away by the molecular maelstrom—curricula which include nothing which peeks beyond the resolution of the optical microscope comes no closer to reflecting the reality of modern biology. The fascination, power and future of biology lie precisely in its range from molecule to community, specifically in its appeal to minds intrigued by the intricacy of multi-causal and multi-leveled analysis—whether in the complexity of macromolecular aggregation and packing, or of matching temporal and morphological pattern in a complex biotic community. Only wide range, multi-leveled training can cultivate this fascination. The core of biological knowledge must be so organized and presented as to drive home the lesson of the past decade—that the combined approaches of several levels are required to crack some of the knottiest biological problems."

Our present first-year course in college biology (Botany and Zoology) is more or less a repetition of the course in General Biology offered to high school students. They often complain that they have seen most of this matter before, namely the grand survey of the plant and animal kingdoms, the dissection of the frog and so forth. It is true however that the college professor does put a greater emphasis on a more detailed and exact study of the structure and function of the various body systems. Yet basically the high school and first year college courses are similar in content and approach. To avoid this difficulty and to give a more modern approach to the teaching of biology on the undergraduate level I suggest and recommend the following curriculum for pre-medical students and biology majors:

First Year:	Cytology Cellular Physiology and Molecular Biology
Second Year:	Genetics Embryology

Third Year:	Histology Comparative Anatomy
Fourth Year:	Physiology Animal Behaviour and Ecology

This arrangement forms a logical sequence from nucleic acids, the master molecules of living systems, to the behaviour of the organism as a whole in its non-living and living environment. It includes a systematic and orderly study of cell structure and function, cell differentiation into tissues and organs, the functions of these organs and body systems, and finally the intra- and inter-specific relations between animals in the complex biotic community. The curriculum is an attempt to combine the new knowledge with the old—nova and vetera. However some aspects of the old knowledge have been deliberately omitted, for example taxonomy and study of plant and animal phyla.

The focus of attention today is not so much on structure and kinds of organisms but rather on the nature of the living system at all levels of organization. This is evident in the new Biological Sciences Curriculum Study (BSCS). In 1959 the American Institute of Biological Sciences set up the BSCS at the University of Colorado to seek the improvement of biological education on the high school level. During the summer of 1960 and 1961, high school and university professors worked at two seven-week Writing Conferences to prepare experimental editions of three separate texts—the Green version which gives strongest emphasis to the community level, the Yellow version to the cellular level, and the Blue version to the molecular level. These texts were used experimentally by 105 teachers with 14,000 students during 1960-1961. Revised editions of the three versions were again used in the following year by 350 teachers with 35,000 students. This summer a final revision will be made and then the texts will be made generally available for classroom use.

All of these new high school texts involve a new approach to the subject matter with less emphasis on organ and tissue in biology and more stress on the community, cellular, and molecular level. When the texts were used experimentally by the teachers they devoted more than half of the class time to exploratory investigations and a number of open-ended experiments.

This new method of teaching high school biology seems to be a good introduction to the proposed college curriculum, and perhaps some of the ideas of the BSCS can be incorporated into the undergraduate course for biology majors. By a multi-leveled training—molecular, cellular, and supercellular—we will be educating the biologists of the future for a multi-leveled analysis of the nature of the living system.

JAMES A. MCKEOUGH