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The Role of Form and Function in the Collegiate Biology Curriculum

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INTRODUCTION

Form and function are usually regarded as essential, but routine, items in a curriculum. They seem less important now than before the rise in interest in molecular biology and ecology. Those of my age group can recall the morphological drudgery of introductory zoology that involved drawing, with a 4-H pencil, typical representatives of the various animal phyla and labeling their parts with parallel guidelines and properly printed names. The aim of such a course seemed to be to produce these illustrated sheets rather than to understand either the organisms or relationships among them. I plodded through these sterile and boring assignments knowing that somewhere along the line, in later courses, I would be introduced to content that would synthesize this mass of detail and lead to a conceptual understanding of morphology and its application to the living world. Later I was to find this a vain hope. Ultimately I had to make my own synthesis.

Fortunately the days of the dissect, look, draw, label and memorize type of laboratory are drawing to a close. The formaldehyde smell and the lanolin covered hands are less a requirement for biology than in the past hastened, perhaps, by the observation that formaldehyde is carcinogenic. As a graduate assistant in the formaldehyde and shark era I found myself exposed several times a week to barrels of preserved specimens in the atmosphere of isolation and privacy given the laboratories of dissection in science halls. Changes in introductory courses have come about slowly and largely independently in various colleges and universities. This does not mean that guidelines for improvement did not exist. It does mean they went largely unheeded. To understand the climate for change one needs to examine activities that have been underway for close to a century designed to improve the caliber of biology programs. To this end one must review the work of committees, commissions, and studies that looked at the status quo and made recommendations. The following section highlights the more significant efforts focused on the biology classroom.

A BRIEF REVIEW OF STUDIES ON INTRODUCTORY BIOLOGY

Many efforts have been made to place objectives in some kind of orderly pattern. Attempts to delineate cognitive and affective objectives for biology can be traced to the ancient Greeks, see Moore (p. 483). However, serious study of the subject in the United States can be traced to about 1890 according to Hurd (1961, p. 9). Hurd's work is a major, but little known, contribution to biological education, applicable to all levels from elementary school through college. Its value as a source of generalizations about the content of a collegiate biology course is due, in part, to the early congruence of curricula in secondary schools and undergraduate colleges. At the turn of the century almost every student who graduated from high school continued education in a college or university, making the major objective of secondary schools one of preparing students for higher education. Prior to 1900 only 3.8% of the school population aged 14 to 17 years was enrolled in secondary schools and there were about 2,500 high schools in the United States. By 1900 the number of schools had increased to 6,005 and 8.4% of the 14 to 17 year old age group was enrolled in high school, with enrollment of girls exceeding enrollment of boys by 25%. In New York State, between 1896 and 1900, 82.5% of high schools taught botany, 70% physiology, 42.5% zoology and 10% biology, so that a variety of opportunities in the biological sciences were readily available to students. As high schools were essentially college preparatory they reflected collegiate biases in their curricula. Colleges themselves were spared examination. The significant early literature regarding introductory collegiate courses varies from nonexistent to sparse. However, what was going on within the college of the time is reflected in the curricula of secondary schools. It would not be unfair to note that the study of secondary school biology curricula of the period is also a study of introductory collegiate biology in the absence of usable data concerning collegiate introductory courses. The criticisms and suggestions for improvement focused on the secondary schools were, by and large, as applicable to the collegiate introductory course, if not also to the entire collegiate curriculum.

Reports of the National Education Association

Concern about the quality of biology education initiated a series of studies of secondary curricula that now span almost a century. The first significant study to concern itself with the life sciences was that in 1893 when the National Education Association formed a Committee on Secondary School Studies, also known as the Committee of Ten. This was headed by Charles W. Eliot, President of Harvard University. Subcommittees were formed to deal with specific disciplines and, for the teaching of zoology, the subcommittee emphasized form and function. While the outline of the year's course was essentially phyletic, the students were to examine the external anatomy of animals. In addition to study of the general form, regional parts and symmetry were also to be stressed. The approach was basically comparative, with one animal compared to others of the same species to determine points of variation and compatibility together with comparison with other types. Simple physiological experiments were also to be a part of the curriculum. Laboratory work was considered an essential and students were to be subject to both a written and laboratory test. The Subcommittee on Physiology suggested a one semester course in each of anatomy, physiology and hygiene with an emphasis on practical work that stressed the mechanics of physics and chemistry of the body. This committee separated physiology from botany and zoology, which it regarded as sciences of description and observation, and placed it more with chemistry and physics as a science of experiment.

In 1896 the National Education Association's Department of Natural Science Instruction was organized. The president, Charles E. Bessey, was concerned that science should be something more than accumulating facts. More attention was to be given to the classification, arrangement and generalization from facts. In short, the development of what was termed a "judicial state of mind." This approach was confirmed by a science committee sponsored by the National Education Association in 1898 under the Chairmanship of E. H. Hall of Harvard. This 1898 committee expressed the opinion that the minute anatomy of plants or animals or specialized work of any kind would be premature and out of place in a high school course of one year in length. Rather, the work should confine itself to the elements of the subject, the principles and methods of thought. John M. Coulter, Chairman of the Subcommittee on Botany in Secondary Schools, severely criticized the common practice of examination and recitation on the gross structure of flowering plants accompanied by herbarium observations. He felt these superficial and restricted and even an irrelevant presentation of biological science. By extension, his recommendations could apply to similar practices in the zoology class.

These studies at the secondary school level represented an early attempt to develop both cognitive and affective objectives for education in the biological sciences. Then, as now, there was little study of science courses at the collegiate level due, in part, to the resistance on the part of collegiate content specialists to any interference with the way they interpret their disciplines. However, collegiate faculties then, as now, were expressing deep concern regarding the inadequate preparation of students entering college. In 1895 the National Education Association appointed a committee of 24, consisting of 12 university scientists and 12 high school teachers, to consider college entrance standards. The major objective of this committee was to explore ways in which secondary schools could do their legitimate work as schools of the people while, at the same time, furnishing adequate preparation to pupils intending to continue their education in colleges and universities. The subcommittee on zoology reported in 1899. Its members unanimously opposed the textbook method of teaching zoology in which "a large amount of information about animals is acquired thereby in a limited time, and a minimum of attainment and preparation is demanded of the teacher." The subcommittee also opposed the taxonomic approach as it gave the student an exaggerated notion of the importance of structural parts for a limited group of animals and failed to develop biological ideas. The majority of the committee thought that external morphology, life history, habits and the economic importance of animals were of greater interest and value to secondary pupils than the systematic and morphological approach then typical of colleges.

The decade from 1890 to 1900 was greatly influenced by the mental discipline theory of psychological development. Laboratory work, for example, was seen as an ideal procedure for the training and exercising of mental faculties devoted to observation, will power and memory. While the mental discipline approach to learning was rejected by psychologists soon after the turn of the century, laboratory work in a surprising number of institutions still today is conducted for its value for developing "mental discipline." The last decade of the 19th century also focused on a shift away from a natural history approach to what might be called "pure" botany and zoology whose major emphasis continued to be morphological. One must distinguish between studies and implementation. The assumption cannot be made that teaching practices or course curricula immediately respond to committee recommendations. Periodically, committees are formed to report on the state of education and most of these reports are read and filed, rather than acted upon.

Recommendations of the American Society of Zoologists

The American Society of Zoologists in 1906 made recommendations for improving the teaching of zoology in the high school. Among these recommendations was that a full year of zoology be taken by the student at secondary school and that it be given for college credit for those continuing their education. The content outline for a year's work in high school zoology, as recommended by ASZ, was:

1. Natural history. Structure in relation to adaptation, life history, and geographical range; the relation of plants to animals and economic relations.
2. Classification of animals by phylum, major classes and, in the case of insects and vertebrates, prominent orders.
3. General plan of external and internal structure for at least one vertebrate (fish or frog) in comparison to that of the human body; an arthropod, an annelid, a coelenterate and a protozoon.
4. General physiology of the above organisms and comparisons with human physiology and with the life processes in plants.
5. Reproduction of protozoa, hydroids and the embryological development of the fish or frog.
6. Evidence of relationships suggesting

evolution and a few facts on adaptation and variation. This recommendation was presented with the strange caveat that "the factors of evolution and the discussion of its theories should not be attempted."

7. History of biology presented as an optional inclusion dealing with major discoveries and the careers of eminent naturalists.

Both form and function were prominent in the recommendations of the American Society of Zoologists. Structure was to be presented in relation to adaptation, classification and evidences of relationships, with specific investigations of the structure of representative organisms coupled with a study of their general physiology. Reproductive physiology and anatomy were also to be investigated on the basis of representative organisms so that form and function were pervasive throughout the six initially recommended content groupings. ASZ also stressed the need for laboratory facilities and, where other studies, such as that of NEA in 1895, unanimously opposed the textbook method of teaching, the ASZ stressed the necessity for a good textbook. It is interesting to note that two-thirds of the course was recommended to consist of laboratory and notebook work. The notebook, to be submitted at examination time, was to contain carefully labeled drawings of the chief anatomical structures studied, thus placing a high emphasis on details of form and on the drawings which were essentially dull and repetitive exercises bereft of intellectual stimulation.

Reactions to committee reports

In an attempt to measure the impact of the Committee of Ten, E. G. Dexter, in 1906, examined 80 courses of study in biology prior to 1895 and 160 courses of study in 1905. He found, in contrast to the Committee of Ten's recommendations, that physiology courses in high school had actually decreased 50%. In addition, while more high schools were teaching botany and zoology, the courses were not being offered for a full year as had been recommended and, most importantly for form and function, biology teachers had reacted against the morphological approach suggested as desirable by the Committee of Ten.

Despite the fact that the members of the Committee of Ten were well known scientists, that the membership of the committee was the largest in the history of education at the time, that the report had been well advertised, had wide readership, and had been the center of many educational discussions, little was achieved by it. This situation is not much different from reactions to current reports recommending changes in content and approach for biological education.

H. R. Linville (1910) in his article "Old and New Ideals in Biology Teaching" made the following cogent observation:

> The teachers of morphological biology in the schools brought with them from the colleges certain ideas of method. Possibly the lecture system never took strong hold in the schools, but the laboratory method of the college with much of its paraphernalia, did. The consequence of this was that thousands of young and untrained pupils were required to cut, section, examine, and draw the parts of dead bodies of unknown and unheard of animals and plants and later to reproduce in examination what they remembered of the facts they had seen.

From separate courses to biology?

For the most part, physiology was treated as a separate course from botany and zoology and it experienced, as noted, a decline in enrollments. It was generally disliked by students and was regarded as difficult to teach. Oscar Riddle, writing in *School Science and Mathematics* in 1906 recommended that human physiology be incorporated into the zoology course with more emphasis on physiology rather than morphology. His recommendations were followed by those of Clifford Crosby in 1907 in an article entitled "Physiology, How and How Much." Crosby reported on several surveys he had made on the teaching of human physiology in high school and found a strong negative feeling in students about their physiology courses. Most of the students took physiology before they had had zoology or botany and thus possessed little background for appreciating physiology. He, too, recommended the development of a zoology course unified by a theme of physiology. With three separate courses reduced to two in number the next logical step was to combine the two into a single biology course.

The editors of *School Science and Mathematics* in 1908 polled a number of university biologists who had been involved in the educational as well as the academic aspects of biology regarding the purpose and organization of biology courses. There was a consensus on three points. 1) That a biology course should be adapted to the majority of pupils. 2) That the course should stress general educational values and be practical and focused on broadening of pupil interests and the deepening of their appreciation. 3) That the course should be focused more on the ideas and principles of the discipline rather than on its details. This poll did not settle the issue of a single biology course incorporating botany, zoology and human physiology. Instead, there were still options for "sub-courses" in each field, either each field for a third of a year or a year's work in each field.

Report of the Central Association of Science and Mathematics Teachers

A Committee on Fundamentals was established by the Central Association of Science and Mathematics Teachers in 1910. The result of this committee's work incorporated suggestions for greater emphasis on reasoning rather than memorization, more attention given to developing problem raising and problem solving attitudes on the part of students, greater emphasis on the relationships of the subject to everyday life without commercialization or industrialization of science, more emphasis on the unfinished nature of science, including the great questions yet to be solved by investigators and, lastly, less attempts at coverage. The course would progress no further than students can go with understanding.

This comment concerning "coverage" appears in a number of reports as a part of an ongoing debate on breadth versus depth in education. With the passage of years and the increase in the amount of material to be covered, critics of breadth note an increasing superficiality, with consequent lack of understanding. While a monomolecular film of coverage may indicate an instantaneous exposure, it does not necessarily follow that comprehension has been achieved as well. Those critics of depth criticize what they regard as attempting an understanding of very few biological topics. However, most university curricula are organized on the principle of depth rather than breadth. The proliferation of specialized topics has been ridiculed by citing such progressions as from courses in morphology, to those in vertebrate morphology, to those in mammalian morphology, to those in carnivore morphology, to those in canine morphology, to those in carnassial tooth morphology. It is obvious that both the proponents of the monomolecular film of content spread over the entire corpus of biology and those whose specialty is so narrow as to ignore all but a single facet of the discipline are in error when their approach is applied to an introductory biology course. Such a course it is clearly understood, cannot be all things to all persons. Content, then, becomes a matter of selection to illustrate major concepts and principles with excursions in depth in a few selected areas.

The 1910 Central Association of Science and Mathematics Teachers report suggested great principles to which students should be exposed. These were:

1. Growth and progressive development, both individual and racial.
2. Division of labor and differentiation for efficiency.
3. Sexual differentiation and its meaning.
4. Economic dependence of man on other organisms.
5. The value of social combination and service.
6. The natural processes of the human mind itself in passing from observations to conclusions.

The role of form and function in illuminating these great principles would be left to the individual instructor.

By 1910 general trends were apparent, in almost all recommendations regarding curriculum content, as follows:

1. The teaching of biology should be oriented towards principles, ideas and interrelationships.
2. More emphasis should be given to scientific methodology and the processes of science. (A recommendation being realized within the American Society of Zoologists through this Science As A Way Of Knowing program.)
3. The establishment of practical objectives for biology teaching.
4. Emphasis attached to capitalizing on student interests and experience and a rejection of the mental discipline theory of learning.

Within the secondary schools the argument of breadth versus depth had definitely been settled in favor of breadth, as physiology failed to become established as a separate course in the curriculum and was combined in some fashion with the existing zoology course. Morphology was still the study of preserved specimens, a practice deprecated by Oscar Riddle in 1906 when he stated "And what objects do our students handle and how do they handle them? I answer that in the majority of laboratories they use dead unyielding specimens which have centralized within themselves all the rigidity that is within the power of over-proof spirits to impart."

NEA Committee on Natural Sciences

The National Education Association in 1913 appointed ten high school teachers, three university professors, three normal school instructors and a physician to study the secondary school curriculum. Remember, that such a study also reflects on introductory collegiate programs, as high schools were, and in some instances still are, patterning their curricula upon those of colleges and universities in their immediate vicinities. Despite the fact that only about half of current high school graduates go on to college and of these smaller fractions concentrate in science and still smaller fractions in the biological sciences, the high school curriculum in large measure still remains a microcosm of collegiate introductory work. For all intents and purposes then, criticisms and recommendations for the high school biology curriculum at this time can equally well apply to collegiate introductory programs.

A major recommendation of this 1913 NEA Committee on Natural Sciences was that unity of subject matter in any course in science was of prime importance. Only in this way could underlying principles be seen to apply over the broad spectrum of the discipline. Secondly, a recommendation was made that biology should include plants, animals and man as living organisms. By the 1930s and 40s, however, humans had almost disappeared from collegiate biology courses. Storer's classic textbook, *General Zoology*, first published in 1943, devotes 21 of its 832 pages to mankind in a terminal chapter 33, which was unlikely to be reached even by the most ardent proponents of coverage. Perhaps the discarding of mankind as a suitable subject of biological study was based on the desire to shun anything that had practical or applied values because of its potential vocational trend. Abstract knowledge for its own sake was considered Aristotelian and proper. Applied knowledge was segregated in courses in human anatomy and physiology of primary interest to nurses, premeds and others who proposed to make some use of their course content.

The 1913 NEA committee, however, recommended that constant references should be made to applications of biology to human welfare and convenience. Included in the objectives for such a course was the recommendation that each pupil become familiar with the structure, function and care of his own body so that form and function of an applied nature became a desideratum. The committee saw nothing wrong in a human biology. It also criticized many common teaching practices such as the use of laboratory work simply to keep students busy or class work confined to a single text within the four walls of the classroom. Committee members were concerned that "The most important consideration is that the course should be conducted with a live teacher." The emphasis on teaching of biology for its importance to human welfare made physiology come to mean human physiology and hygiene. By now space in the curriculum was being found for topics such as ecology which were being included at the expense of morphology.

Breakdown of collegiate/secondary school relationships

In the first two decades of this century collegiate and secondary school instructors worked rather closely together. Research biologists were frequently involved in curriculum recommendations but, after about 1920, high schools and colleges parted company, at least as regards such close cooperation. The high school was developing its own identity and while it still looked, and still does look, to college curricula for guidance, continued recommendations that biology become a more practical course and criticism of the miniature college course taught at the secondary level greatly affected the high school curriculum while having little, if any, effect upon that at the collegiate level. This changing relationship of the high school and the college communities can be demonstrated by examining the membership of two committees on science teaching. In 1893 the Committee of Ten consisted of five college or university professors and/or scientists, three high school teachers, one normal school teacher and one superintendent of schools. By 1920 the Committee on Reorganization of Science in Secondary Schools, which consisted of 47 members, included 24 high school teachers or administrators, 11 college or university professors and/or scientists, 6 normal school teachers, 5 superintendents of schools, and 1 business representative, further demonstrating the increase in involvement in the construction of science courses on the part of public school personnel and the lessened potential influence of representatives from colleges and universities, a disjunction that was not remedied until the establishment of the Biological Sciences Curriculum Study in 1958.

Not all educators and scientists found the emphasis on the practical and the applied to be sound. John Dewey, addressing the National Education Association in March of 1916, expressed a concern that the basic contribution of science would be lost in the rising emphasis on practical and applied content. He expressed this as follows:

> The entire cogency of their position depends on the identification of science with a certain limited field of subject matter, ignoring the fact that science is primarily the method of intelligence at work in observation, in inquiry and experimental testing; that, fundamentally, what science means and stands for is simply the best ways yet found out by which human intelligence can do the work it should do, ways that are continually improved by the very process of use.

Recommendations of the North Central Association of Colleges and Secondary Schools

Reports on the state of science education accumulated until they began to sound like a broken record. They focused largely on the need for emphasis of principles and generalizations and the involvement of students with the application of biological principles to problematic situations. Emphasis shifted from the content imposed by the discipline to meeting the needs of the student and presenting principles selected from those most important in the day-to-day life of citizens. The biology committee of the North Central Association of Colleges and Secondary Schools in 1931 recommended six biological principles to fill these needs as follows:

1. The adaptation of organisms to their environment.
2. The germ theory of disease.
3. The interdependence of organisms.

4. The cell as the structural and physiological unit of living things.
5. The theory of evolution.
6. The distinctive characteristics of living things.

While these recommendations did not specifically isolate form and function as a major principle, cellular structure and function was a desideratum and adaptation and the distinctive characteristics of living things implied knowledge of form and function. Morphology, per se, however, continued to be deemphasized in a trend discernable as far back as the beginning of the century.

The committee was realistic in its approach, recognizing that, while principles provided a sound and practical focus of biology teaching, acceptance of such recommendations was not guaranteed. It expressed concern that teachers were not interested in spending the time necessary to develop an understanding of a principle. Rather, they chose to have students memorize large masses of unorganized facts which were easy to teach and simple to evaluate. Colleges were perceived as part of the problem, as their entrance examinations consisted primarily of questions focused on the recall of facts. The committee observed that college science classes were not taught from the point of view of the consumer of science and that, therefore, teachers at the secondary level were not prepared to make use of science as it applies to problems encountered by students. Further, such emphasis could have negative effect on college admissions and student's subsequent performance in classes devoted to rote memory.

Office of Education "Instruction in Science"

The difference between promise and fulfillment was underscored by a publication of the Office of Education, United States Department of the Interior in 1933 entitled "Instruction in Science." An investigation of biology curriculum objectives demonstrated they were laudable but unfulfilled. The six major objectives most frequently listed included:

1. Acquiring knowledge that will produce a better understanding of our environment.
2. Presenting knowledge that will function to achieve the cardinal principles of secondary education as defined by the Commission on the Reorganization of Secondary Education (Caldwell, 1920).
3. Developing an appreciation of nature and of individual responsibility in the world.
4. Acquiring knowledge of the fundamental principles of biology.
5. Developing an interest in nature.
6. Developing the ability to think scientifically.

Despite the enunciation of objectives reiterating still earlier recommendations, visits to biology classes showed that teachers still asked questions that could be answered in one word and which were primarily focused on the parts of either plants or animals. Details of morphology still dominated the curriculum and examinations measured only the students ability to remember isolated facts. The biology laboratory work was also centered on detail and typically requested copying pictures from the textbook, a pointless and stultifying exercise.

The report of the National Society for the Study of Education

In 1932, the National Society for the Study of Education (NSSE) issued a 364 page report entitled "A Program for Teaching Science." This committee was chaired by S. Ralph Powers and explored questions on science teaching at every level from kindergarten to college. Course content was to be selected in terms of its applicability and should illuminate the major generalizations of science as well as relating to the welfare of human beings. The committee recognized that content should not only have a practical value, but cultural and liberalizing values should be stressed as well. In terms of laboratory work, it, too, should be directed toward problem solving and be focused on providing students with science experiences, rather than on simply being illustrative or confirmatory of what had already been presented in either lecture or textbook. Again, a series of biological principles was considered as fundamental. This time nine such principles were elucidated as follows:

1. Energy cannot be created or destroyed but merely transformed from one form to another.
2. The ultimate source of energy for all living things is sunlight.
3. Microorganisms are the immediate cause of some diseases.
4. All organisms must be adjusted to their environmental factors in order to survive in the struggle for existence.
5. All life comes from pre-existing life and reproduces its own kind.
6. Animals and plants are not distributed uniformly nor at random over the surfaces of the earth, but are found in definite zones and in local populations.
7. Food, oxygen, optimal conditions of temperature, moisture and light are essential to the life of most living things.
8. The cell is the structural and physiological unit in all organisms.
9. The more complex organisms have been derived by natural processes from simpler ones. These, in turn, from still simpler and so on back to the first living forms.

It can easily be seen that the NSSE program for teaching science had principles that paralleled those developed by the North Central Association for Colleges and Secondary Schools in 1931. Evolution and the germ theory of disease are common to both as are adaptation and the focus on the cell. Here again, form and function are not specifically delineated except in relation to the cell but are implicit in coverage of other principles. Despite recommendations of prestigious committees and commissions, science examinations continued to reflect emphasis on naming parts, giving functions, arranging in order, or defining terms, indicating that emphasis was still basically on the vocabulary of form and function and the principles and concepts were left for students to derive from large masses of unsifted data.

Union of American Biological Societies Committee on the Teaching of Biology

The disparity between what was actually done in the classroom and the recommendation of "experts" in the field of science and science education is nowhere better demonstrated than by responses to the Committee on the Teaching of Biology of the Union of American Biological Societies questionnaire published in 1942. Responses to the questionnaire were received from 3,186 biology teachers and two sets of data are especially revealing. In the first, the teachers felt that the greatest classroom emphasis in general biology should be on (1) Health, disease, hygiene; (2) Physiology; (3) Heredity; (4) Conservation; (5) Structure. This confirmed the emphasis on form and function which was apparently still taking up some 40% of classroom instructional time. Secondly, that classroom practice differed from that recommended is clearly noted in the nature of the topics to which the teachers gave the lowest rating in terms of emphasis. These were: (1) Eugenics; (2) Behavior; (3) Scientific method; (4) Photosynthesis; and (5) Biological principles. In short, the principles approach so highly recommended by study groups was the least used in classroom presentations of any of the recommendations.

Cooperative Committee on Science Teaching

During World War II the Cooperative Committee on Science Teaching was established. It included representatives of the American Chemical Society, The Mathematical Association of America and the Union of American Biological Societies among others. Despite its war time slant toward practicality, it developed a series of instructional goals not too different from those recommended earlier. These included:

1. Structure, function, care, first aid and nutrition of the human body.

2. Bacteria and disease.
3. Personal and public health.
4. Use of plant products as food, medicine, shelter, and clothing among other uses.
5. Genetics as exemplified by plant and animal breeding.
6. Conservation of soil, grasslands, forest, wild life and flood control.
7. Applied ecology.

In this report the study of structure and function was primarily related to the human body and such topics as evolution and the cell were only incidental.

Trends toward scientific literacy

When one examines the recommendations made by the many committees and commissions studying introductory science courses two trends can be discerned. Recommendations from committees composed primarily of scientists requested more time be given to the social implications of science, supported a balanced program of physical and biological sciences, and suggested special attention be given to the talented student and potential scientist. In addition, the scientists on these committees recognized that the nature of science, its methods and place in the social and economic life of individual citizens was of growing importance.

Those committees composed principally of educators looked upon science as a means for meeting the "needs" of individuals. They spoke of making science functional in the lives of young people. However, they, too, considered that the methods and techniques of the scientist were valuable procedures for solving problems of daily living and suggested that scientific attitudes were worthy goals for all students at all levels.

In the 1930s, new ways of presenting introductory collegiate biology were being developed in a few institutions. At the University of Chicago, under the leadership of Robert Maynard Hutchins, a general education program was developed that broke with tradition to develop what was considered a more meaningful introductory course. At Yale, George A. Baitsell also developed an innovative approach to an introductory course emphasizing human biology. It should be remembered that biology, per se, did not constitute an identifiable discipline within colleges and universities until the early 1920s when the first college biology for general education was offered at Stanford University. Biology courses were not common enough even to promote the preparation of texts in the subject for use at the collegiate level. Except for the experimental programs of the 1930s, most universities introduced students to life sciences through either botany or zoology. It was not really until the 1950s that biology as a recognizable discipline was common enough to foster the production of biology textbooks, one of the first of which was Garrett Hardin's *Biology, Its Human Implications*(1952).

Every committee which studied biology curricula supported, wholly or in part, the importance of science in the maintenance of a free society and democratic ideals. All felt such support would be accomplished through the preparation of a citizenry informed in science and by maintaining an adequate supply of scientific and technical manpower. However, despite good intentions, the expected widespread curriculum reforms in science curricula and improved teaching procedures did not materialize.

Between 1950 and 1960 it was recognized that few of the major problems of modern civilization could be dealt with in the absence of scientific literacy. The realization that an understanding of science was imperative in the education of all people was beginning to be apparent, although how this understanding should be communicated was unclear.

Southeastern/North Central Conferences on Biology Teaching

The Southeastern Conference on Biology Teaching held during the summer of 1954 brought together 85 high school and college teachers. Six biological scientists prepared written summary statements of how their special fields could and should contribute to the improvement of biological education. The six fields were:

1. Heredity and development.
2. Evolution and paleontology.
3. Morphology.

4. Taxonomy.
5. Physiology and health.
6. Ecology and conservation.

Morphology and physiology together constituted a third of the special fields considered of value in biological education.

In 1955 at Cheboygan, Michigan the North Central Conference on Biology Teaching involved 87 persons including high school science teachers and college biology teachers. Its work closely paralleled that of the Southeastern Conference, with research biologists invited to prepare papers as background resources. There was a consensus that current scientific developments and social trends should influence the content of biology courses, that course adjustments are needed to meet the problems of urbanization, and that the whole biology course needed to be upgraded in terms of intellectual content.

NAS/NRC Committee on Educational Policies

The National Academy of Sciences National Research Council (NAS/NRC) established, in 1954, a Committee on Educational Policies which recognized a need for agreement among educators and scientists as to what constituted biology in courses at high school, college and graduate levels. This committee also felt that a basic knowledge of biology should be the part of everyone's education. Just as in the time of Mondino (p. 643), the committee expressed concern about the extensive vocabulary found in biology courses and stated "One of the shortcomings of textbooks and courses is often that the student may become so impressed with need for learning a new vocabulary as to lose sight of larger objectives. Moreover, much confusion has arisen in use of terms and units in biology simply because of the way biology has grown. . . . Authors and teachers, meanwhile, have a special problem and a special responsibility in regard to terminology."

A Subcommittee on Instructional Materials and Publications of this NAS-NRC committee concerned itself with the role of the laboratory in introductory biology and stated ". . . even in some colleges, the pressures of mounting enrollments and inadequate facilities, the ineptitude and lack of enthusiasm of some teachers, the notion that students learn as well from demonstrations and films as from laboratory work they do themselves, have led to drastic reduction or even total abandonment of laboratory and field study. Elsewhere, though 'laboratory' remains on schedule, what is offered is so pedestrian and unimaginative, so unlikely to challenge the student's powers as to be almost worse than no laboratory work at all." The latter part of this statement at least categorizes my own experience with introductory zoology laboratories and it is distressing to find this trend continuing into 1954 and beyond.

Source Book of Laboratory and Field Studies in Biology

In an attempt to provide more challenging laboratory opportunities a writing conference was held at Michigan State University during the summer of 1957. A writing team composed of ten biologists from colleges and universities worked with twenty high school biology teachers to produce what was called the *The Source Book of Laboratory and Field Studies in Biology.* None of the major eight outlined topics was concerned primarily with form and function, although both would play a part in the major areas of investigation which were designed as follows:

1. Organisms living in their particular environments are the primary subjects of biology.
2. The diversity of organisms.
3. Some essential chemistry.
4. The organism as a dynamic open system: introduction to the basic organismic functions.
5. Maintenance of the individual.
6. Maintenance of the species.
7. The organism in its ecological setting.
8. Evolution of organisms and their environments.

Physiology was stressed over morphology, with students learning to report observations, experimental findings and interpretations as an important phase of laboratory and fieldwork. Further, laboratory and field studies were to be integrated with reading, discussion, consultation with resource persons, and evaluative procedures so that they were perceived as equivalent learning procedures rather than isolated confirmatory events.

Still, the plethora of studies and recommendations went largely unheeded, primarily because they acted as sheets of instructions on which others were supposed to take action. It became quite apparent that continuing to produce recommendations and expecting others to implement them would be the same chance proposition as having a baby and leaving it on someone else's doorstep to raise according to the desires of the natural parents.

The Biological Sciences Curriculum Study

A turning point came in 1955 when the American Institute of Biological Sciences appointed an Education and Professional Recruitment Committee which was charged not with making recommendations but with the development of a program of biological education at all levels. This was to be a comprehensive curriculum project involved with course content, laboratory manuals and teacher aids. It would produce films, film strips, charts and models. It would study in-service training of teachers and the possible production of pamphlets, booklets and other publications to serve to increase the effectiveness of biological education. Oswald Tippo was chairman of the AIBS Education Committee and a Steering Committee, composed of research biologists, high school biology teachers, educators and school administrators, was appointed under the chairmanship of H. Bentley Glass, then of Johns Hopkins University, and Arnold B. Grobman of the Florida State Museum who served as Director of the Biological Sciences Curriculum Study (BSCS) which began in 1958.

The emphasis on production of materials rather than a specific course of study was a departure from the previous efforts primarily aimed at making recommendations. Early on, the Biological Sciences Curriculum Study developed themes that should be pervasive in any biology course. These themes, as valid today as when they were elucidated in 1960, are as follows:

1. Change of living things through time, evolution.
2. Diversity of type and unity of pattern among living things.
3. Genetic continuity of life.
4. Complementarity of organism and environment.
5. Biological roots of behavior.
6. Complementarity of structure and function.
7. Regulation and homeostasis, the maintenance of life in the face of change.
8. Growth and development in the individual's life.
9. Science as inquiry.
10. Intellectual history of biological concepts.

The BSCS themes reemphasized the importance of form and function but related both to broader goals. Diversity of type and unity of pattern focused both on commonality of structure and adaptations of it in diverse organisms. The complementarity of structure and function related form and function as an operating unit and avoided morphology for morphology's sake and physiology solely as the interpretation of experimental results. Regulation and homeostasis and change of living things through time also imply a knowledge of form and function both in terms of geologic time and within organisms facing environmental changes in today's world. A biology course organized to deal with form and function in terms of principles of unity and diversity offered an alternative to routinized memorization of structure and confirmational experimental work in physiology (Mayer, 1986).

It was never envisioned that these themes would become headings for chapters that would encapsulate an idea which then would never again appear in the text. This was the case with the infamous chapter on "the" scientific method which opened so many textbooks for so many decades. It gave the student an apparent recipe for scientific infallibility which never again was referred to in the text. The very concept of themes implied that these major ideas were to be interwoven throughout the text and emphasized wherever applicable so that the student would meet them again and again and, by their ubiquitous nature, become familiar with them as basic recurring principles of biology with applicability throughout the living world.

The time was right for a change. Biology courses were woefully out of date and, through neglect, had become routine exercises in mediocrity. This was widely recognized but no alternatives had been made available. Except for those exceptional instructors who, on their own, strove to remedy defects as they saw them, the biology courses of the 1950s were scarcely distinguishable from those of the 1930s except, that in some cases, a biochemical terminology had been substituted for one dealing with gross morphology.

The BSCS produced materials focused on the secondary school because this was the first time most students encountered biology as a discrete discipline. It was interesting to observe the effect new materials at the secondary level had on the entire educational continuum. It would be expected that elementary schools would respond to changes at the secondary level but, for the first time, the river began to flow backwards. Traditionally, high school textbooks were simply watered down collegiate ones. A simpler vocabulary sufficed to turn an introductory college text into one usable in a high school. In the case of the BSCS, however, the secondary school texts were so revolutionary that writers of collegiate texts had to take cognizance of them (BSCS Newsletter #42, 1971). Thus, college textbooks began to be written that reflected the changes instituted at the secondary level. It took a few years for BSCS trained high school students to reach college and, when they did, they expressed dissatisfaction with courses that had been unchanged for decades. Student unrest in the 1960s and 70s has been almost exclusively ascribed as being political in nature but, in part, it was also academic as students appreciated that cut and dried, routine memorization neither reflected the world as they saw it nor was it likely to be responsible for productive change.

Why was the BSCS successful? Why, practically from its inception, did it enter the curricula of 50% of American schools directly and almost 100% indirectly as its works influenced curriculum content? Although Sputnik convinced many that U.S. science was falling behind that of the Soviet Union, the primary answer has to be that BSCS was a concerted activist effort. The first that attempted to change, on a nationwide basis, the curriculum of secondary schools. It capitalized on the studies and reports that had gone before and its aim was to produce materials that reflected the current state of the discipline of biology within a matrix of teachable pedagogy. It combined distinguished scientists with outstanding biology teachers. The need was considered so great that the BSCS attracted many members of the National Academy of Sciences, a Nobel Prize winner, and outstanding research biologists representing a broad variety of fields who were willing to work to improve the biology curriculum. Further, because BSCS was a national effort it received national publicity not only in journals devoted to science such as *Bioscience* and those devoted to education such as *The American Biology Teacher,* but also in the public press as well, including *Time* magazine.

This well publicized effort involved scientists and teachers from all over the United States in a task that sorely needed to be done (Mayer, 1978). Funding from the National Science Foundation made such an effort possible and the success of this project in inducing classroom change is well documented (Shymansky, 1984).

The Commission on Undergraduate Education in the Biological Sciences (CUEBS)

This was also a time of general educational ferment in the sciences, with curriculum projects engaged in preparing materials for chemistry, physics, earth sciences, and a variety of other disciplines at levels from elementary through high school (K–12). In addition, the need was felt for change in the collegiate introductory course. After all, the collegiate course had profoundly influenced courses offered at the secondary level and criticisms of secondary courses were implicating college courses as well. The Commission on Undergraduate Education in the Biological Sciences (CUEBS) was established to look into the collegiate program. However, during its seven year existence CUEBS neither developed a textbook nor postulated specific content and emphasis. Because of the nature of education at the college and university level more general recommendations were made with outlines of typical courses given as models.

Biology in a liberal education. The Commission on Undergraduate Education in the Biological Sciences produced a number of publications dealing with specific aspects of college biology teaching. Publication #15, for example, edited by Jeffrey J. W. Baker, dealt with biology in a liberal education and reported on a colloquium held at Stanford University 2–13 August 1965. This report is of particular significance in relation to the introductory collegiate biology course primarily designed as a contribution to the liberal arts. It is interesting to note that no agreement could be reached on topics so fundamental that they should appear in any introductory biology course. However, analysis of course outlines submitted at the colloquium noted that virtually all contained units on anatomy and physiology, the nature of science, metabolism, photosynthesis, genetics, developmental biology, evolution and ecology.

With one or two notable exceptions, few professors attending the colloquium indicated satisfaction with the coverage of the major plant and animal phyla. One solution suggested was to eliminate the phyletic survey. Another was to de-emphasize anatomical and morphological detail and, instead, emphasize the experimental aspects of biology, applying specific anatomical detail only where relevant. If materials on plant and animal phyla were deemed pertinent and were to be included, each phylum might be discussed in terms of a specific organism used to attack current research problems. For example, the squid might be discussed in terms of use of its giant nerve fiber in neurophysiological research. A few participants felt that covering certain biological principles such as transport in both plant and animal forms simultaneously was a great mistake. Instead, they felt it essential that such processes, initially at least, be treated on the level of the whole organism. All participants agreed that subject matter should be included that would give the student an understanding of biology as an investigative science and that such subject matter should make students aware of the vast scope of biology.

Further, all participants were aware of the changes taking place in biology. Some viewed emphasis on molecular biology as posing a threat to content concerned with morphology, taxonomy, phylogeny, and so forth. Others, however, welcomed the newer material. This skewed opinion about content was expressed by one participant as follows:

> I think that the poor teaching of classical biology by molecular biologists is worse than the poor teaching of molecular biology by classically oriented biologists.

As regards the perennial question whether there should be one introductory course offered to majors and non-majors alike, the initial attitude toward non-majors was that they should receive an appreciation of the scope of biology, its history and philosophy, its current problems and probable future. It follows that such insights are probably even more important to the biology major. Although this was not a primary topic of discussion it was generally agreed that the non-science major should not be exposed to the course traditionally given to the major but, rather, that both majors and non-majors should receive a newly designed course that would impart an overview of the field and its vast potential for intellectual growth and achievement in order to provide continuing appreciation of the discipline for the non-major and the enrichment of participation on the part of the major.

Core curriculum for biology majors. In addi-

TABLE 1. *Form and function topics in the core curriculum of four universities (Purdue, Stanford, Dartmouth, and North Carolina State).*

Amylase and starch digestion	Iodine test for starch
The nerve impulse	Membrane permeability
Sliding filament theory of muscle contraction	Composition of DNA
Cilia and flagella	Structure of proteins
Cell organelles	Structure of ribosomal RNA
Erythrocytes	Structure of starch, cellulose, glycogen, fats, phospholipids and steroids
Structure of prokaryotes	DNA replication (Meselson and Stahl experiments)
Bacterial cell wall	RNA and protein synthesis (Nirenberg experiments)
Structure and composition of a phage	Amino acid activation and binding to sRNA
Structure and composition of the nucleus	mRNA binding to ribosome
Plasma membrane (Robertson's Unit Structure)	sRNA-AA complex binding to site on mRNA by base pairing
Growth and structure of the cell wall	Activation energy and enzymes
Structure and function of the Golgi apparatus	Chlorophylls a and b
Endoplasmic reticulum	Light reaction of photosynthesis (Van Niel's hypothesis, Hill reaction)
Mitochondria	Electron excitation and splitting of the water molecule
Cytoplasm	Oxidative phosphorylation
Role of the electron microscope in the study of cell structure	Structure and reproduction of slime molds
Use and care of the compound microscope	Chromosomal aberrations
Cyclosis	Cytokinesis
Electron transport	Mitosis
Krebs cycle	Problems of synapses
Energy yield and ATP balance in respiration	Heterospory in *Selaginella* and *Equisetum*
Products of energy metabolism	Chiasma formation during meiosis
Glycolytic pathway of Embden-Meyerof	Cytological analysis of meiosis
Glucose metabolism	Egg differentiation in oogenesis
Energy coupling of ATP synthesis	Angiosperm gametogenesis
Respiration rates	Life cycle of *Neurospora*
Neuron structure	Nuclear role in egg development
Muscle ultrastructure (the sarcomere)	Factors influencing growth
Leaf and stem structure	Growth as synthesis of protoplasm
Structure and physiology of *Paramecium*	Cell division as an aspect of growth
Seed and root structure	Bacterial growth phases
Fern gametophyte structure	
Diatom structure (*Pinnularia*)	
Volvox structure	

tion to considering biology within the liberal arts, CUEBS also investigated, in publication #18, the content of a core curriculum in biology for majors (1967). The core curricula of four universities (Purdue, Stanford, North Carolina State, and Dartmouth) were closely investigated. Subject matter was broken down into categories, topics, and subtopics. Table 1 lists those topics which primarily related to form and function and which all four universities included in their core.

Table 1 excludes many items relative to genetics and to plants, but of the total number of topics listed in publication #18 only a small fraction were included by all four institutions surveyed. If one picks, instead, topics which three of the four institutions included in their core, the list becomes appreciably lengthened. However, this would be a poor way to pick course content because of the way items were listed in the study. For example, Purdue and Dartmouth were listed as the only two institutions providing a definition of life, but North Carolina included characteristics of living matter and systems and Stanford presented attributes and characteristics of the living organism. Perhaps all three topics are saying the same thing in different ways so that a detailed analysis depending only on specific combinations of words, may conceal that the same topic is being covered but simply being reported differently.

A major recommendation concerning the content of the curriculum was coverage of fundamental biological concepts including, at all levels of biological complexity, structure–function relationships, growth and development, the nature of hereditary transmission, the molecular basis of energetics, synthesis and metabolic control, the relationship of organisms to one another and to their environment, the behavior of populations in space and time, and evolution. These generalized recommendations show a great deal of similarity to those made in earlier studies pertaining to the secondary school, such as the BSCS themes. The difference, however, is that the core curriculum was designed to cover two years of training for majors while the introductory course would be for no more than a year and could well be for majors and nonmajors alike.

Modules in college biology teaching. CUEBS also investigated the use of modules in college biology teaching (Creager and Murray, 1971). Modules can be considered tools of instruction. They are self contained, independent units with primary focus on a few well defined objectives. Modules provide opportunities for organizing experiences meeting the needs and interest of teachers and/or students. The modular approach provides a way of assessing student's learning progress, reduces routine aspects of instruction, allows for easy updating of study material, relatively easily can be developed by teachers and can be exchanged between institutions. Among the most well known of the modular approaches to biology is the minicourse program developed at Purdue University by Sam N. Postlethwait.

The laboratory. CUEBS publication #33 (Thornton, 1972) was entitled *The Laboratory: A Place to Investigate.* This work deals with laboratories in introductory courses, advanced courses, field stations, and two year community colleges. It delineates the laboratory curricula at Marquette University and at MIT. In the investigative laboratory, activities parallel lectures and text simultaneously to unearth content. Some laboratory programs have been completely uncoupled from introductory lecture courses while others are closely integrated with the lecture course. CUEBS deliberately set out to identify alternatives to traditional undergraduate programs, particularly those for teaching the art of investigation within an institutional environment whose usual practices are not supportive of this educational goal.

The context of collegiate biological education. The final CUEBS report, #34 (Cox and Davis, 1972) constituted a comprehensive view of the then studied undergraduate biological education which could be subsumed in one word "paternalism." CUEBS concluded that the instructor still holds his position as the knowledge authority knowing that what is being done is best for the student while, at the same time, choking off student opportunities for academic maturity, educational self direction, and intellectual growth. This report, entitled *The Context of Biological Education: The Case for Change,* included many recommendations and suggestions all based on programs actually in existence in identified college biology departments. While these recommendations would be anathema to those who regard recall as the highest form of intellectual achievement and the collection of unrelated facts a the goal of education, their announced goals of undergraduate biology education challenge the voice of authority as being valued more than independent judgment and question whether there is always a single unambiguous right answer to a question.

The Transient Nature of Reform Efforts

One of the positive features of the BSCS, in contrast to CUEBS, is that it has remained in existence since its inception in 1958. All other similar programs disbanded with the altruistic hope that they had done their work, made their impact, and further effort on their part was no longer needed. The fates of these programs have proven otherwise, for only vestiges of their work remains. Curriculum revision at any level is not a one time process but, rather, one that requires continuous presence and effort. There is no way that a series of widely spaced, unrelated efforts at curriculum revision can produce desired changes during the decades between such revisions. The gearing up for such individual efforts is a costly and time

TABLE 2. *The fifteen most important science topics as ranked by secondary teachers of biology in a 1982 study by Finley* et al.

1. Photosynthesis	9. Digestion in animals
2. Mitosis/meiosis	10. Hormonal control of reproduction
3. Cell theory	11. Chemistry needed for biology
4. Cellular respiration	12. Complementarity of structure/function
5. Animal circulatory systems	13. Leaf structure and function
6. Mendelian genetics	14. Food chains and webs
7. Chromosome theory of heredity	15. Respiratory systems in animals
8. Gene concept	

consuming process which is not necessary if there is a continuing entity designed to monitor content and pedagogy, and to change objectives in keeping with new knowledge in order to meet the needs of a given population at a given time. That only one of the NSF's sponsored curriculum studies remains intact from the number begun in the late 50s and early 60s is, to some extent, a testament to futility. Just as one battle does not win a war, so one curriculum effort does not ensure implementation and change in subsequent time periods. The BSCS was initially eminently successful and continues to make contributions to the improvement of biological education, but a revival of the effort at the collegiate level begun by CUEBS would be a welcome contribution to the improvement of introductory collegiate biology.

Importance vs. *difficulty*

Studies relative to biological education still continue. Many are concerned with the same issues on which this paper has already reported. Those concerned with biological content are ones of import to this presentation. In 1982, Finley, Stuart and Yarroch polled 100 secondary teachers of biology, chemistry, physics and earth science. They were asked to rate the 15 most important science topics and 15 topics most difficult to teach. For biology, the 15 important topics ranked as shown in Table 2.

While the poll did not elicit answers in a way that could be easily quantified, three of the top items of importance related to the cell (2, 3, and 4) and of these mitosis/meiosis and cell theory are classical inclusions traceable to the development of the cell theory by Schleiden and Schwann. Three of the important inclusions concerned genetics (6, 7, and 8) with 6 concentrating on the work of Mendel and the other two presenting information at least decades old. DNA, per se, does not make the list unless somehow it's hidden within items 7 and 8. Only two items relative to plants are considered of importance (1 and 13) and here 13 is a rather pedestrian inclusion undoubtedly listed as necessary to provide a place for photosynthesis to occur. Despite all of the publicity about pollution and preservation of the environment only item 14 concerning food chains and webs, can be considered ecological.

Form and function, however, constitute at least a third of the items considered of importance. One deals with a generalized topic of complementarity (12) and four are directly related to specific study of structure and function of systems (5, 9, 10, and 15). This gives evidence of the background of teachers and their concern with the classical. The coverage of structure and function of specific organ systems indicates no new synthesis of materials or its presentation around organizing principles. Circulation and respiration are not combined as part of an overall transport system nor are digestion and respiration presented in terms of energy. Hormonal control is discussed primarily in terms of reproduction, but not as an overall part of a coordinating mechanism involving the nervous system. Information listed as of importance is still of the scrappy and uncoordinated nature criticized by the Committee of Ten in 1893. Even a casual perusal of this list elicits concern about the items not regarded as important and gives an impression that a

TABLE 3. *The ranking of fifteen topics secondary teachers thought most difficult as shown in the 1982 study by Finley* et al.

1. Cellular respiration	9. Chromosome theory of heredity
2. Protein synthesis	10. Probability in genetics
3. Mitosis/meiosis	11. Mendelian genetics
4. Chemistry necessary for biology	12. Taxonomy and classification
5. Enzyme structure and function	13. Dihybrid crosses
6. Photosynthesis	14. Homeostatic systems
7. Hormonal control of reproduction	15. Population genetics
8. Multiple alleles	

student of the 1930s would be very comfortable 50 years later in one of these classrooms whose work apparently still parallels the course outlines of half a century ago.

The 15 topics teachers thought most difficult are ranked in Table 3. It is interesting to compare what teachers thought was important with what they thought was difficult and there seems to be a correlation between difficulty and importance, almost as if the interpretation were "if it's hard it must be important." Almost half of the items considered important were also considered difficult to present. Cellular respiration, mitosis/meiosis, chemistry necessary for biology, photosynthesis, hormonal control of reproduction, the chromosome theory of heredity, and Mendelian genetics appear on both lists.

Five items concerning physiology are considered difficult to present (1, 2, 5, 7, and 14). Six items concerned with genetics present difficulties (8, 9, 10, 11, 13, and 15). Only one item relative to plants (photosynthesis) seems both difficult and important. Taxonomy and classification are presented as difficult when perhaps what is really meant is they are dull or uninteresting to students who have no motivation for their study. Difficult subjects are usually considered to be dull or boring or uninteresting either because they are not presented properly or because they are perceived as leading nowhere. The difficulty, in short, may not be so much with the topic itself, but the way in which it is presented. The implied criticism may not be so much due to the subject matter but the pedagogy used to present it. It is interesting that none of the structure–function topics listed as important (4, 5, 8, 9, 12, and 15) are listed as being difficult to present. Hormonal control of reproduction is the only item construed as physiological which appears on both lists. Apparently, then, teachers find form and function topics important but not difficult.

It must be remembered that difficulty also can be equated with degree of nonfamiliarity. This was adequately demonstrated by the molecular biological approach introduced into secondary schools by the BSCS in 1960. Almost uniformly teachers decried the interpolation of molecular biology because of its difficulty—difficult because they had no background or training in molecular biology. While all things are supposedly new to the student, what is new to the teacher becomes a learning experience that poses difficulty. However, because many of the topics listed above as difficult are practically standards in the biological repertoire—dihybrid crosses, taxonomy and classification, for example—these cannot be difficult because the teacher is unfamiliar with them. From a perusal of the list it appears that modern biological concepts (post-DNA) may not be part of the curriculum at all and therefore escape categorization as either important or difficult.

Recent recommendations

Berkheimer *et al.* (1984) delineate four science objectives for the non-specialist as follows:

1. Overcoming the fear of science.
2. Developing capacity for critical thinking.
3. Finding and using reliable sources of scientific data.

4. Gaining scientific and technical knowledge for professions and civic responsibilities in an increasingly technological society.

In different words, such recommendations have been made before and there is no indication that these will be accepted and implemented any more than have those previously made. Koballa, undated, presents an analysis that reveals that emphasis on discrete knowledge is characteristic of all the programs investigated, indicating little or no improvement in a situation deplored for almost a century.

Fortunately, there are attempts to modify traditional approaches to biology. Flashpohler and Swords (1985) have developed an introductory collegiate course that deals with issues in social biology such as human reproduction, genetics, transplants, immunology, hormones and drug effects. Practicality and applicability characterize this type of presentation. Moll and Allen (1982) at West Virginia University have organized a course around developing critical thinking skills. Their introductory program emphasizes the application of knowledge, the making of predictions and the drawing of conclusions.

Concern for undergraduate collegiate biology courses is not confined to the United States. The International Union of Biological Sciences Commission for Biological Education reflects global concerns in its *A Strategy for Biology Courses for Undergraduate Non-Biology Majors* (1987). Using a curriculum hypothesis that does not start from scientific subjects but, rather, from life situations in which a student is likely to become involved, the question is posed as to what kind of knowledge a citizen needs in order to master the most important situations in life. It is maintained that these situations require a great variety of biological topics for their comprehension. The major objective of this approach is "to motivate non-biologists to appreciate the importance and usefulness of an understanding of biological sciences in their lives and their roles in society."

Subsumed under this major objective is a comprehension of the functioning of a healthy body and an appreciation of the great extent to which people are a part of, and dependent upon the natural environment around them. Further, as in studies cited previously, the report notes:

> It is important that non-biologists should be led to appreciate the methodology of science, its scope and limitations, and to appreciate that science has a methodology, which combines rational processes with intuition and ethical values in a unique way. Science is a mainly logical process supported by repeatable, experimental evidence, developed by rigid training and practice.

Scientific methodology is envisioned as having applications beyond the realm of science. The report states "The methodology of science can and should be applied to social administration, business, and other public activities which require reasoned decision making, taking into account all relevant constraints, but recognizing that in public affairs moral and aesthetic considerations have to play an important role." This publication illustrates the appreciation of global deficiencies in our approach to biological science and its applicability, particularly in terms of the education of those who are not destined to be scientists.

Many modern investigations are emphasizing cognitive research findings and attempting to incorporate them into instruction. For example, Linn (1986) emphasizes need for increase in quantity of science instruction and on deeper coverage of topics that then result in better learning. Mestre (1987) deplores the lack of use of cognitive research data. He feels that, among the major obstacles to the changes that cognitive research can direct, are changes in textbook design affecting classroom performance by deemphasizing coverage and rote learning, and changes in tests to reduce measurement of factual and quantitative material, and to provide increasing opportunities for exercise of cognitive ability.

The applications of cognitive research are recent additions to our concerns about instructional improvement. As a relatively young addition, whose data and approaches are still being debated, it shows promise. However, what data we have on cognition are as unlikely to find immediate use in an introductory biology program as have other recommendations. Without concerted effort, and in the absence of motivation for change, the introductory course is likely to proceed in slow Darwinian steps rather than to experience a saltational jump or one dictated by rapid movement in a period of punctuation of equilibrium.

Once again, some colleges are engaged in the exploration of innovative introductory biology programs. One example is afforded by Stanford University. Supported by the Ford Foundation, Stanford, in 1969, initiated its Department of Human Biology and developed a highly popular course in human biology at the introductory level. The course brings together studies on the human, previously scattered throughout numbers of university departments, into one focused on the biology of humans broadly interpreted as involving the social sciences, psychology, and other pertinent disciplines.

References to studies and recommendations regarding introductory biology: Armacost and Klinge (*1956), Baker (*1967), Beauchamp (1932), Berkheimer *et al.* (*1984), Bessey (1896), Bigelow (*1906), BSCS (1971), Breukelman and Armacost (*1955), Caldwell (1920), CUEBS (*1967), Cox and Davis (*1972), Creager and Murray (1971), Dewey (1916), Dexter (1906), Downing (1931), Finley *et al.* (1982), Fisher *et al.* (*1986), Flashpohler and Swords (1985), Galloway (*1910), Grobman (*1969), Hall (*1898), Havighurst *et al.* (1943), Hurd (*1961, 1978), IUBS/CBE (*1987), Koballa (undated), Linn (1986), Linville (*1910), Maienschein (*1986), Mayer (1978, *1986), Mestre (*1987), Moll and Allen (1982), NEA (*1893), Peabody (1915), Powers (*1932), Riddle (1906), Shymansky (1984).

Objectives and Content of an Introductory Biology Course

The importance of unlearning

One of the first problems in dealing with any discipline involves not what needs to be learned but what needs to be unlearned. Objectives and content of our introductory course must take cognizance of the fact that students come to classes with folk wisdom and a variety of misunderstandings garnered from folklore which may be reinforced by various media presentations. Sometimes the misrepresentations are made by groups with which the student may have had contact and whose presentations they had uncritically internalized without recognizing them as special interest pleadings designed to further a particular dogma by thinly disguising it as having scientific merit. In many cases, the mislabeled educational baggage a student brings to a course is ignored, creating conflicts as a student is faced with new information at variance with that already possessed, without any mechanisms offered for the evaluation of what might, in the student's mind, be polar positions.

Kitcher (1984) takes cognizance of the knowledge a student may bring to the classroom as follows: "Our beliefs are a product of processes in which our early training, encounters with the world, and constructive thinking all have parts to play. We observe the lore of our community and count ourselves justified as we modify the things we are taught in the light of our experience." It is these beliefs that are frequently challenged when students are exposed to knowledge of which they had been previously ignorant. Unfortunately, many times the student's preconceptions are derided and dismissed without new information sufficiently convincingly presented to take its place. This creates a quandary for the student as cherished beliefs are cast aside but not effectively replaced or modified by the data that challenge the preconception. In many cases the student is cut loose from a comforting, if inaccurate, view of the world without being provided an adequate anchor for new conceptions that ultimately could prove even more personally satisfying.

Student misconceptions

Some student misconceptions result not from prior knowledge, or lack thereof, but from misunderstanding the presentation of new material. In some cases it is safe to say that a student may acquire more misinformation than information from an introductory course. Fisher *et al.* (1986) dealt with problems of misconceptions of college students. Misunderstandings about evolution frequently result from erroneous prior knowledge as do misunderstandings of the role played by heredity and environment. For example, some students when polled felt that heredity accounted for some 50 to 80% of physical characteristics but, when questioned about mental characteristics, only 0 to 15% felt that these were determined by heredity. Sometimes the bugbear of vocabulary transmits an unintended message. The term "dominant" in relation to genes was interpreted by students as that the dominant gene "turns off" the recessive which, in the student mind, was equated with its being submissive. The dominant genes were also felt by students to increase in a population, indicating that the Hardy-Weinberg principle had not been internalized.

Students were found also to have problems with terms such as "chromosome" which they applied to decondensed eukaryotic chromatin, to prokaryotic genomes, and to linkage maps. In the metaphase of mitosis the replicated and condensed chromosome was still referred to as being a "pair" of chromosomes. When questioned about DNA, students responded that DNA was made up of amino acids, or that amino acids were products of translocation. Somehow the student, by being exposed to DNA, amino acids and translocation, understood these terms to be related but did not know how.

Such misunderstandings go unnoticed primarily because they are not sought. Objective examinations fail to reveal them as the reasons why a student has missed a question. Instructors may perceive that their presentations have been internalized by the student without ever recognizing that such reception may be faulty and the message garbled to the point of unintelligibility.

The nature of science

The *sine qua non* of the collegiate introductory biology course is to communicate the nature of science. The initial organization of a liberal arts college, or a college of letters, arts and sciences, was epistemological. The objective was to acquaint students with the ways in which humans know about their world and the different systems for obtaining data concerning it. Students were to become acquainted with how such diverse disciplines as history, social sciences, arts and the natural sciences viewed the world. Unfortunately, the liberal arts college strayed from this initial perspective of explicating ways of knowing. Instead, it became enmeshed in detail and minutia in all of its divisions in much the same way as the Laocoon group became enmeshed with serpents. Almost no liberal arts college retains its focus on how knowledge is organized, how various disciplines collect their data, and how comparisons between different systems of knowledge are made. Instead, college divisions and departments have become more compartmentalized and involved with internal soul searching that results in concentrating on the data but not the discipline. It is understandable, therefore, why college graduates cannot distinguish between data of the social sciences and data derived from the natural sciences. Nor can an average college graduate assign degrees of validity and credibility to data derived through certain systems. It is no small wonder, then, that local school boards, state boards of education and state legislators show no ability to distinguish between theological data, as derived from biblical revelation, and scientific data derived from observation and experiment. Their inability to distinguish between different ways of knowing leads them, logically in their minds, to a structurally illogical conclusion that biblical revelation has a place in the science classroom to "balance" the presentation of evolution. This becomes particularly appealing as anti-evolutionists have developed the pseudoscience of creationism whose basis is the Genesis account of creation in the King James version of the Bible. Anti-evolutionists have dignified this biblical story by referring to it as "creation science" readily perceived as an oxymoron by those familiar with the data that support evolution and the absolute lack of scientific data to support "creation science" (Kitcher, 1982).

This confusion is no trivial matter. In states as diverse as California, Arkansas, Tennessee and Louisiana major court cases have been initiated demanding the inclusion of "creation science" in public school classrooms wherever and whenever evolution is discussed. In every court, at every level, the anti-evolutionists have been rebuffed and their position recognized by the courts as a religious one fostered by hyperorthodox Christian fundamentalists. The latest of these cases was decided by the U.S. Supreme Court in 1987 which ruled against Louisiana's "equal time" law. This decision, however, will not serve to terminate the efforts of the anti-evolutionists who prosper from preying on the scientifically naive or illiterate. This scientifically naive population is not an ignorant one and, while it contains relatively few reputable biologists, it has attracted engineers, educators and college graduates from non-science disciplines.

The fact that a purportedly educated population exists incapable of distinguishing science from other ways of knowing and able to confuse science and religion indicates that colleges and universities do a very poor job of delineating ways of knowing, defining science, clarifying its boundaries and assigning credibility to its data. Any science course that does not do these things is failing to achieve the objective for which science was made an undergraduate requirement in the first place. As a humbling exercise, include a question on the biology final examination asking the students to define science. Reading the answers, unless one is satisfied with a canned, meaningless definition such as "Science is a body of organized knowledge," will give an insight as to whether the year has clarified in the student's mind science as a way of knowing. Any course that does not give students an understanding of science as a discipline, including those things science can explicate well and those to which it cannot contribute, does students of the liberal arts no service.

We seem to be in an age of anti-intellectualism, and the National Science Foundation has categorized us as a nation of scientific illiterates. It would be too much to expect that changes in the presentation of biology in an introductory course would turn this situation around. An impact can be made, however, on the population segment addressed if effort is made to orient the course to explicate the nature of science and emphasize rational approaches to problem solving. Many students have inherited from their cultures "anti" biases. It is rare to find that someone actively anti-intellectual is enrolled in college, but anti-scientism is relatively easy to find. The popular image of a mad scientist creating monsters has been replaced by the mad scientist unleashing viruses or mutants upon an unsuspecting population. The fettering of scientific investigation by ignorance becomes more and more common. Negative community reactions to genetically engineered organisms is but one example. Those who deprecate animal experimentation and march under the outmoded banner of antivivisectionism have their own stereotype of science, but I know of no scientist who has sadistic impulses toward animals that are played out in a research laboratory. "Creation science" becomes the banner under which many anti-evolutionists march and rising interest in the occult is fostered by its presentation with a scientific patina.

References to the nature of science: Achinstein (*1968), Ayala and Dobzhansky (*1974), Blake *et al.* (*1960), Braithwaite (1953), Brody (1970), Gallie (*1957), Harre (*1970), Kockelmans (1968), Kuhn (*1970), Madden (*1960), Nash (1963), Northrop (1947), Poincaré (*1952), Stauffer (*1949), Suppe (1977), Suppes (*1969), Toulmin (*1953), Wiener (*1953), Woodger (1937).

Science and pseudoscience

Confusion exists in the student mind not only between science and religion—supposedly easily definable realms—but also in relation to systems masquerading as science. So many attempts are made to give a degree of respectability to nonsense by claiming a scientific base for it that it is no wonder students cannot clearly identify a scientific statement from a non-scientific one. An introductory course must clarify this distinction between science and pseudoscience.

Even college bookstores do not seem to be able to distinguish between science and pseudoscience. On the science shelves can be found such works as those by Velikovsky and Tompkins and Bird, whose *Secret Life of Plants* indicated that conversation raises plant spirits. On many shelves Von Danikin stands side by side with Sagan. What are our introductory science courses doing to distinguish science from pseudoscience? How can a student evaluate the science in a popular work such as *The Double Helix* and contrast it to the sheer speculation present in *The Chariot of the Gods*? Science is not only a way of knowing but it is a way of evaluating. The analytical and evaluative capacities of students are seldom called upon in an average introductory program in which cognizance should be taken not only of what students do not know, but what they know in error. If all students were blank slates on which one could write for the first time, education would be an easier endeavor. But seldom is attention paid to the fact that education is not simply a matter of being exposed to something new, but being exposed to something different and many times contradictory to randomly accreted knowledge accumulated as a part of a student's cultural background.

Health and nutrition

Among the varieties of folk wisdom brought to class by entering college students perhaps none is more common or insidious than folk prophecies concerning health and nutrition. Some of this information is handed down through a family oral tradition. It has tended to take on a pseudoscientific patina, moving away from the sulfur, molasses and mustard plasters of grandmothers to over-the-counter pills and syrups coupled with exercise and behavior regimens designed to ameliorate whatever condition one seems to have. Television ads hawk nostrums of all kinds. Magazines contain advertisements designed to promote medication and mechanisms for weight loss, body building, retarding aging, building breasts and enhancing romance. Patrons of supermarkets are assailed by checkout counter magazines and newspapers, each outdoing the other in pushing unsubstantiated claims designed to provide easy solutions to complex problems. Quack nostrums are touted as a panacea for everything from cancer to AIDS and charlatans become rich because of gullibility enhanced by desperation to try anything that promises relief.

Markets and specialty stores offer expensive foods and potions whose major contribution to the unwary seems to be hope. Expensive and excessive vitamin preparations, foods high in calcium, low in sodium, high in iron, or low in cholesterol dot the shelves. These are welcome, indeed, to persons with such conditions as high blood pressure or osteoporosis on good medical grounds. However, quack "nutritionists" or "dietitians" take advantage of real findings to improve their own fiscal well being. Organic foods and dietary items are a favorite of charlatans as are vegetables and fruit grown "organically" that supposedly will bring roses back to sallow cheeks.

And what has this to do with the content of an introductory biology course and what part does form and function play in relation to what many would feel is consumer science and not real biology? The point is simply this, the large number of gullible and naive individuals influenced by advertisements for items touted as the results of scientific breakthroughs are themselves products of ineffectual backgrounds in science. Do students understand the term "organic" in relation to nutritional requirements of plants and do they have any comprehension that plants are unable to distinguish sources of nitrogen, for example? To the plant, nitrogen is nitrogen, whether it comes from DOW Chemical or horse manure. How does the way a scientist use the term "organic" differ from the way in which the term is used by self styled nutritionists? What are the nutritional consequences of an exclusively vegetable diet or a macrobiotic one? How can all the varied nutritional patterns available in diet books be valid when they contradict one another? What are the essentials of good nutrition and what are the consequences of following fads and fancies? Do students in a biology course understand enough about the functioning of the body to ensure an intake of basic requirements and a rejection of advertising foolishness? At the very least, our presentations of form and function should indicate performance limits and the inability of metabolism to profit by many of the recommendations made in popular literature.

References to health and nutrition: Brown and Goldstein (1984), Eaton and Konner (*1985), Goodhart and Shils (*1980), Kolata (1986), Monmaney (1986), Rechcigl (*1977), Tver and Russell (*1981).

Form and function

While the prime purpose of an introductory science course at the collegiate level is to impart an understanding of science, including both its strengths and weaknesses, the role of form and function in such a course may be less obvious. From the latter half of the 19th century to the present we have accumulated a century of opinions on the role to be played by form and function. From its initial primacy, occupying the majority of time and effort within the introductory course, the emphasis on form and function has waxed and waned but it still occupies a position of importance in almost every introductory course. It would be inconceivable to attempt to explain the living world without reference to form and function which are ubiquitous from the inorganic world through the organic and within the latter from monerans through the most complex of animals at the organ/system level.

One can deal with form and function at the molecular level. In terms of information transfer, one can speculate whether a cell is simply DNA's way of creating more DNA in the same way that there used to be speculation as to whether a hen is simply an egg's way of creating another egg. Such speculations constitute attractive asides but may miss the main point that DNA bears the instructions for what an organism will look like and how it will function and, thus, constitutes a blue print for form and function with the blue print, itself, conforming to a specific structural pattern that follows functional principles.

Form and function can be dealt with at a number of other levels as well. Recognition of form, for example, seems almost an innate property of the natural world. Chemical elements have form recognition of sorts as they bond with one another. Complex compounds, likewise, exhibit a form recognition as the structure of enzymes fits specific portions of complex molecules. Guanine fits cytosine, adenine—thiamine on the basis of form. In the world of organisms, predators recognize prey by sight and some, such as bats, can even recognize their prey by echolocation. Mimicry in certain organisms emulates the form of other species less likely to be preyed upon. Form, then, is a pervasive element within our universe, existing from the atomic to the organismal level and pervading both organic and inorganic realms.

Both form and function display two very contradictory principles. Systematic arrangement of organisms implies a unity of pattern among living things while, at the same time, depending on diversity of type. Aristotle (Moore, p. 489), for example, was able to separate crustaceans from other arthropods but, nonetheless, recognized similarities between both groups. He was also able to do so when separating cephalopods from other mollusks while still recognizing similarities just as he did when he separated cetaceans from the other mammals while still recognizing them as mammals. He recognized unity of pattern when he noted that oviparity united fishes, amphibians, reptiles and birds but he also separated fishes from the other groups by diversity of type noting that they had what he called "imperfect" eggs. A unity of pattern was recognized when Aristotle combined both oviparous and viviparous animals because they had red blood. As more became known about structure and function, principles of diversity of type and unity of pattern were reinforced.

Knowledge of form and function is essential to our understanding of the living world. However, too few organizing principles incorporate form and function into the average introductory course. Diversity of type and unity of pattern is just one principle that can be used to synthesize what is too frequently presented as a mass of unrelated and disorganized data. Vocabulary, a stumbling block for students of form, continues to be a pervasive element in teaching biology. The selection of organizing principles, however, is in part conditioned by just what it is that the introductory course is designed to accomplish. Knowing this, content and areas of emphasis then can be chosen to further the goals of the course. The content of an introductory course is ultimately always a compromise. With an almost infinite amount of information to be covered in a finite amount of time, a course outline can only be a selection of what is considered most important at a given point. To the ancients (Moore, p. 500) the four humors were basic to the understanding of the living world but today they are of only historical interest.

What should be included in an introductory course today? What are the big ideas of biology? What are those facets of the discipline of greatest applicability to the lives of all citizens? What concepts are likely to be retained and prove useful? What subject matter is most likely to develop an understanding of and a sympathy for the biological sciences? What is the role of form and function within the chosen objectives? The answers to these questions form a matrix within which overall objectives of education are subsumed. Never have I heard it expressed that the objective of education is to cram a student with the greatest number of isolated factual details that can be transmitted in a given period of time. Instead, the objectives most likely correspond to high blown platitudes such as teaching the skills of analysis, synthesis and evaluation, developing a critical thinking capacity, demonstrating to students how to learn on their own, and inculcating a sense of the value of knowledge, both abstract and applied.

Vocabulary

Objectives to the contrary, however, the fact remains that form and function, particularly morphology, are detail and vocabulary laden. After almost a century of recommendations to the contrary, vocabulary still dominates the content of many courses. The number of italicized or bold face type words on a typical textbook page bears this out. In just one 17 line paragraph dealing with skeletal muscle a popular and widely used collegiate text confronts the beginning student with a dozen words in bold face type. Guess which of the following twelve will be on the next examination? Antagonistic pairs, flexor, triceps, extensor, adductors, abductors, levators, depressors, pronators, supinators, sphincters, dilators. Another seven line paragraph considers the following five significant enough to appear in bold face: epinephrine, norepinephrine, tyrosine, chromaffin cells, and neurotransmitter.

Vocabulary has been a stumbling block in the study of form since the 14th century when Mondino de 'Luzzi taught at Bologna. Mondino dissected both animals and human bodies primarily to verify the Latin anatomical works that had been translated from the Arabic. In doing so, Mondino came across a problem that continues to bedevil teachers and students of anatomy. The many terms for organs, structures or processes made Mondino's students as unhappy as they make students today. Despite the fact that the terminology saves time and space, the proliferation of words, words, words frequently focuses attention on the name rather than the object and saddles students with the burden of memorizing a vast vocabulary of form and function without the necessity of understanding either. As Mondino was reintroducing the study of the form and function of the body to the Western world he needed new words and these he took mostly from Arabic and Hebrew, transmuting the names into Latin forms. Thus, the students of form and function in the 13th and 14th centuries faced vocabulary as a demanding ritual of memory, as is still sadly the case in many anatomy and physiology courses today.

Mondino's terminology, however, was much more complicated than that of today, suffering not only from involved construction, but debased Latin combined with confusing nomenclature which makes his book extremely hard to read. For many parts he has several names. The sacrum, for example, is variously called *alchatim, allannis,* and *alhavius.* Conversely, the same name is often used for several parts. *Anchae,* for example, could mean the hips or the pelvic skeleton or the acetabulum or even the corpora quadrigemina.

Many of the Arabic terms employed by Mondino were in common usage until the revival of the Greek language in the 15th and 16th centuries. Mondino's now obsolete terms included such as *mirach* for the anterior abdominal wall, *siphac* for the anterior layer of peritoneum, and *zirbus* for the great omentum. In his works Mondino also included terms of classical origin that had been in use through the Dark and early Middle Ages, such as *longaon* for rectum. For many of these classical words Mondino supplied false etymologies. He attributes *colon,* for example, to the medieval Latin word *cola* (cellule) when, in fact, it was a Greek word meaning primarily an organ, although both Aristotle and Pliny used it in its present meaning.

Fortunately, today we are spared the battle of vocabularies and our anatomical synonyms are mercifully few. Specific names for specific structures or parts of structures have become codified and simplified and have practically universal comprehension among students of form, except in those countries where nationalism has so affected their language that special words are coined with no prior meaning within the country of use and no applicability beyond its borders. The creation of scientific terms in Hindi and in Tagalog, a major source of the manufactured language of the Philippines, are examples of this trend. In France a Secretary of State for Francophone affairs and a General Association for the Users of the French Language are concerned with the linguistic purity of the French language. In the fields of science, commerce, and high technology new French words are created to replace terms that are not French in derivation.

If this trend continues we may some day see a return to the type of warfare waged in the past on behalf of Latin and Greek against Arabic anatomical terms during the 16th century. Then words became symbols of two cultures, the Arabist and the Humanist. As the Humanists were gaining the upper hand, new experimental anatomy was being developed and the exponents of this new science exhibited the same virulence against the Humanists as the Humanists had shown against the Arabists. Although the furor over anatomical terminology can well be regarded as a tempest in a teapot, there are those who regard it as a *sine qua non* of anatomy. Historically, however, without the Arabists Western science would not have been preserved throughout the Dark Ages. Without the Humanists, 16th century anatomists would have had to start from ground zero, or at least a much lower level than that at which they were able to begin.

Anatomical vocabulary still has not been fully purged of Arabic terms. Numbers of them still exist but so Latinized or Graecized as to be hardly recognizable. Singer (1957) considered this a case of protective mimicry in the world of words. *Basilica, cephalica, retina, saphena* and *sesamoid* (the open sesame of the Ali Baba story) are such Arabic words still extant in our anatomical vocabulary. To the Arabs we must also credit clavicle, true and false ribs, iris, pia mater, dura mater, matrix and mesentery.

Tracing the words employed in the study of form can be an illuminating experience showing relationships of Greek, Latin, and Arabic vocabularies that have formed the body of today's anatomical nomenclature. Single, specific words now exist for single specific structures. The beginning student may perceive this nomenclature as nothing more than a plethora of detail. But it is simplicity itself when compared to the murky, indefinite applications of vocabulary from a variety of sources applied in a quixotic fashion that characterized early morphology. Several names for a single structure or worse, a single name for several structures are no longer the problems they were. The present-day problem is not precision of nomenclature but, rather, the plethora of detailed terminology whose memorization occasionally passes for comprehension of anatomical concepts.

It has been estimated that toward the end of the 19th century about 50,000 anatomical names were in use for some 5,000 structures in the human body. Such a vocabulary load retarded the study of anatomy. But, by 1895, a list of about 4,500 terms was accepted at the Basle Conference. This system of nomenclature is known as the *Basle Nomina Anatomica,* usually abbreviated B.N.A. and is in Latin. Subsequent revisions have occurred, with that undertaken in Britain as the *Birmingham Revision* or B.R. in 1933 being the best source of translations of Latin terms into English. In Paris, in 1955, international agreement was reached on a Latin system of nomenclature based largely on the B.N.A. This *Nomina Anatomica,* was subsequently amended in New York in 1960 and translated into English. The principles involved in the new N.A. are (1) that, with very few exceptions, each structure shall be designated by one term only, (2) that every term in the official list shall be in Latin with the option that each country is at liberty to translate the official Latin terms into its own vernacular for teaching purposes (an option that has resulted in problems of intercountry communication), (3) that the terms shall be primarily memory signs with preferably some informative or descriptive value and (4) that eponyms shall not be used. This latter principle removes the use of personal names for structures. They are used quite haphazardly and give no clue as to the type of structure involved. In addition, they are frequently misleading historically because, in many instances, the person commemorated was, by no means, the first to describe the structure. For example, what was called Wirsung's duct was referred to by Mondino some 300 years before Wirsung. If there were persistence in the use of eponyms, red blood corpuscles would be called Swammerdam cells; the collecting tubules of the kidney—Bellini tubules, mast cells—Ehrlich cells, and so on.

The question may well be asked concerning the amount of vocabulary that the average student not destined for medical school or for further study of structure should know. In terms of the skeletal system, for example, the names of the major bones of the body would seem appropriate as it makes a difference whether one is talking about a fractured humerus or a fractured femur, but it would be difficult to rationalize, in dealing with the femur, that a student should also be familiar with such terms as greater trochanter, lesser trochanter and intertrochanteric crest. Similarly, location and function of major muscle groups might provide both valuable and useful knowledge to understand how the body moves in terms of extensors and flexors, adductors and abductors. But, here again, mindless learning of origin, insertion and action of each muscle in the human body is such a pedantic exercise that even those whose field is myology are sometimes caught referring to reference works to refresh their own memories prior to the day's lecture on muscles.

Centuries have been devoted to descriptive morphology, from the time of Neolithic observations of gross external and internal anatomy. Closer and closer observation with magnifying lens and microscope revealed more structural detail from organs to tissues to cells and intracellular content. Each new discovery was worthy of being named. It is understandable in terms of discoveries of structure that the names, themselves, should become an end rather than simply a means of communicating information.

Only in the last few decades has there been a noticeable deemphasis on vocabulary and more emphasis on concept and principle. We have come full circle to asking larger, rather than smaller, caliber questions as Moore (p. 493) has noted was something Aristotle did—seek answers to big questions.

For those of us who have had to go through life with a head cluttered with useless terminology, one wishes this vocabulary deemphasis had started earlier. As a professional biologist for more than 40 years I've never had one occasion in my entire career to use such a term as "adambulacral ossicles" (the bumps on the upper surface of starfish) in any substantive way, although it may have currency among those who study echinoderms. Similarly, the only use I've ever had for protopodite, endopodite, and exopodite has been to show off at a lobster dinner at a seafood restaurant. Somehow, Huxley's serial homology and the differentiation of a simple biramous appendage became lost in a welter of detail that sometimes included, not only the names of the three basic parts of the appendage, but the names applied to each jointed segment of each appendage.

Unfortunately, this is not an extreme or unusual example, and it accurately exemplifies the loss of the forest among the trees. Mercifully, physiology has been spared much of the climate of minutia so common to morphology due, in part, to its being a more experimental discipline in contrast to the observational nature which, initially at least, characterized morphology. In physiology an experimental result is the desideratum, in contrast to locating and naming a particular line, eminence, duct or pore. Descriptive morphology relied on names, experimental physiology on results. As Moore (p. 567) has pointed out, form and function developed as contemporaries. Once an organ was identified, questioning became focused on its function and its place among other organs. Form did not exist without function nor, obviously, function without form, but both became obscured by a fog of verbiage.

References to vocabulary: Effler (1935), Field and Harrison (*1957), Nomina anatomica (*1961), Singer (1957), Skinner (*1961), Wain (*1958).

DIVERSITY OF TYPE/UNITY OF PATTERN AS AN ORGANIZING PRINCIPLE OF AN INTRODUCTORY BIOLOGY COURSE

This paper has discussed themes, objectives, principles and content recommended for inclusion in an introductory biology course. Just as the entire course needs major objectives that permeate all of its aspects, so subtopics need organizing principles. For form and function, diversity of type and unity of pattern tie seemingly unrelated observations and conclusions together and can serve as an organizing principle.

In organizing a presentation of form and function there are many pathways that can be followed. However, there appear to be basic elements that should be common to all. The following pages present types of coverage that emphasize basic ideas and serve to tie seemingly unrelated data into a meaningful whole. By no means are these to be taken as a course outline. They are to serve merely as examples of how form and function topics can be made more meaningful to an introductory student by grouping data into related clusters under a unifying concept.

Prokaryotes/eukaryotes

The primary organismic dichotomy, prokaryotes *vs.* eukaryotes (Fig. 1), is based on observation of structure and function. Both in structure and in biochemistry eukaryotes and prokaryotes differ by far more than the presence or absence of a membrane bounded nucleus. Table 4, from Margulis and Schwartz (1982), presents the structural and functional features of this division which has been characterized by Stanier *et al.* (1963) as "this basic divergence in cellular structure which separates the bacteria and the blue green algae from all other cellular organisms, probably represents the greatest single evolutionary discontinuity to be found in the present day world." Although the division was proposed in 1937 by Edouard Chatton, a French marine biologist, this dichotomy has yet to find its way into some introductory biology programs. There are still some for whom the primary division of organisms is into plants and animals as when one played the game Animal, Vegetable or Mineral, in which all the planet's objects could be categorized under one of these three headings. The Margulis (1982) use of five kingdoms is today scarcely enough. Margulis recognized only a single kingdom of prokaryotes, the Monera, with the other four kingdoms (the Protoctista, Fungi, Plants and Animals) comprising the eukaryote kingdoms. Current researches will undoubtedly lead to the creation of other kingdoms. Current researches will undoubtedly lead to the creation of other terms much in the same fashion as the kingdoms of eukaryotes are defined. Such taxonomy exemplifies diversity of type and unity of pattern at a basic level and uses

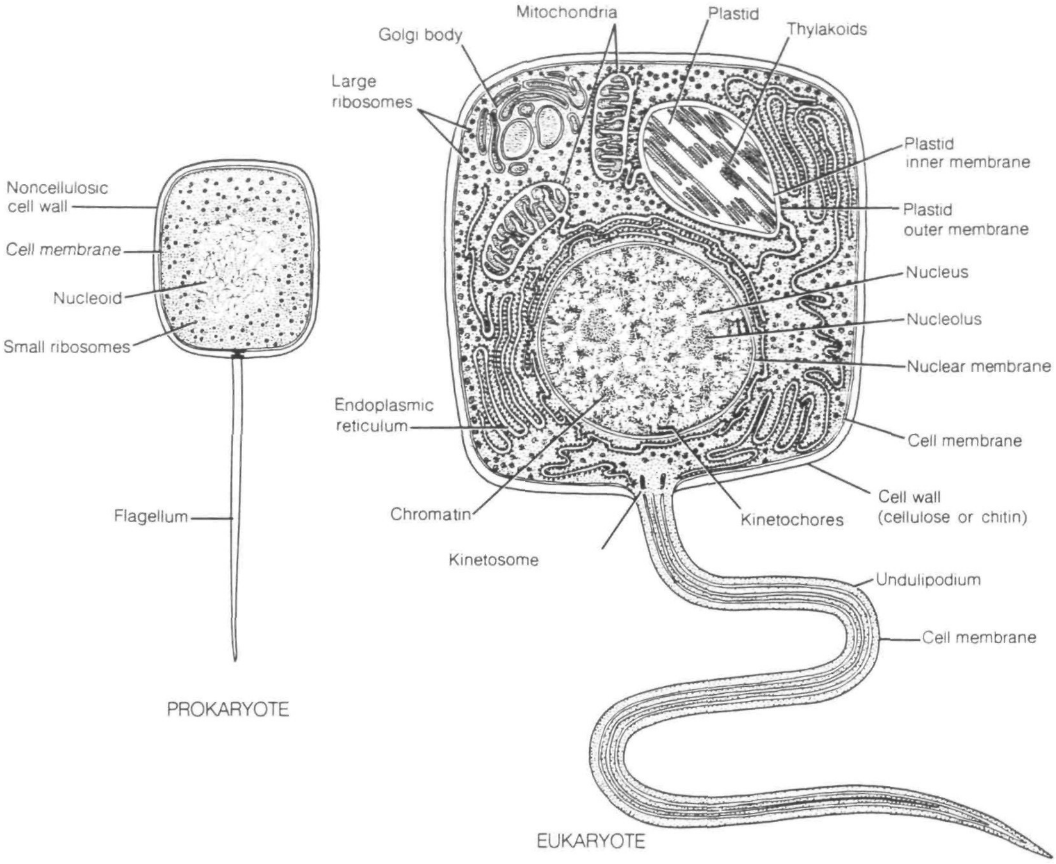

FIG. 1. The primary dichotomy of living organisms is represented by their division into prokaryotes (left) and eukaryotes (right). These cell drawings are based on electron microscopy. Every prokaryotic or eukaryotic cell does not display all the features shown here. Unity of pattern and diversity of type is represented at the cellular level in this very early separation of organisms based on cell type. (Margulis, 1982, p. 9.)

knowledge of both form and function to account for organismic similarities and differences.

The cell

Basic structure and function permeate biology. Every student should understand Virchow's doctrine that cells come from preexisting cells. The cell theory of Schleiden and Schwann provides a diversity of type pervading the organic world. To understand a cell is to understand an organism and to understand a single cell is to understand trillions of cells. The cell theory is basic to biology and practically all biological phenomena can be elucidated from a single cell. Just as Huxley used the crayfish as a model animal, one can use the cell to illustrate biological principles.

If one considers the cell as a basic unit of structure and function and as an example of diversity of type (Fig. 2), one must also consider unity of pattern exemplified at the cellular level. If there is such a thing as a standard cell, its ability to exist in a myriad of forms and to specialize for all living functions demonstrates the plasticity of living material. Too frequently students think in terms of fixity of form and function and ascribe an unchanging structure to an epithelial or to a muscle cell, for example. The ability to clone an entire organism from one of these "fixed" epi-

TABLE 4. *Major differences between prokaryotes and eukaryotes (Margulis, 1982, p. 7).*

Prokaryotes	Eukaryotes
Mostly small cells (1–10 μm). All are microbes.	Mostly large cells (10–100 μm). Some are microbes; most are large organisms.
DNA in nucleoid, not membrane-bounded. No chromosomes.	Membrane-bounded nucleus containing chromosomes made of DNA, RNA, and proteins.
Cell division direct, mostly by binary fission. No centrioles, mitotic spindle, or microtubules.	Cell division by various forms of mitosis; mitotic spindles (or at least some arrangement of microtubules).
Sexual systems rare; when sex does take place, genetic material is transferred from donor to recipient.	Sexual systems common; equal participation of both partners (male and female) in fertilization. Alternation of diploid and haploid forms by meiosis and fertilization.
Multicellular forms rare. No tissue development.	Multicellular organisms show extensive development of tissues.
Many strict anaerobes (which are killed by oxygen), facultatively anaerobic, microaerophilic, and aerobic forms.	Almost all are aerobic (they need oxygen to live); exceptions are clearly secondary modifications.
Enormous variations in the metabolic patterns of the group as a whole.	Same metabolic patterns of oxidation within the group (Embden-Meyerhof glucose metabolism, Krebs-cycle oxidations, cytochrome electron transport chains).
Mitochondria absent; enzymes for oxidation of organic molecules bound to cell membranes (not packaged separately).	Enzymes for oxidation of 3-carbon organic acids are packaged within mitochondria.
Simple bacterial flagella, composed of flagellin protein.	Complex 9 + 2 undulipodia composed of tubulin and many other proteins.
In photosynthetic species, enzymes for photosynthesis are bound as chromatophores to cell membrane, not packaged separately. Various patterns of anaerobic and aerobic photosynthesis, including the formation of end products such as sulfur, sulfate and oxygen.	In photosynthetic species, enzymes for photosynthesis are packaged in membrane-bounded plastids. All photosynthetic species have oxygen-eliminating photosynthesis.

thelial cells, however, adequately demonstrates their potential. The plasticity of cells is reflected in entire organisms. For a student to be able to watch an aquatic, gilled, legless herbivore turn into a terrestrial, lung breathing, four legged carnivore as happens when a tadpole turns into a frog, provides a simulated window through which one can observe changes in form and function as a characteristic of the living world.

References to the cell: The field of cellular biology is advancing so rapidly that any book over one year old is out-of-date in terms of recent advances. While standard texts cover the basic cell adequately, only journals can keep up with day-to-day advances. Among the journals covering the various cell studies are:

Cell (biweekly)—Cell Editorial Offices, 50 Church St., Cambridge, MA 02138.

Cell Biology International Reports—Academic Press (London) Ltd., High Street, Foots Cray, Sidcup, Kent DA 145HP, England.

Cell Differentiation—Elsevier Scientific Publishers Ireland Ltd., P.O. Box 85, Limerick, Ireland.

Cell Structure and Function—dist. by Elsevier Scientific Publishers, P.O. Box 211, 1000AE, Amsterdam, The Netherlands.

Cell and Tissue Kinetics (bimonthly)—Blackwell Publications Ltd., Osney Mead, Oxford OX2 0EL, England.

Cell and Tissue Research—Springer-Verlag, 44 Hartz Way, Secaucus, NJ 07094.

Analogy / homology

The concept of analogy and homology is pervasive in the study of form. The beginning biology student is, by and large,

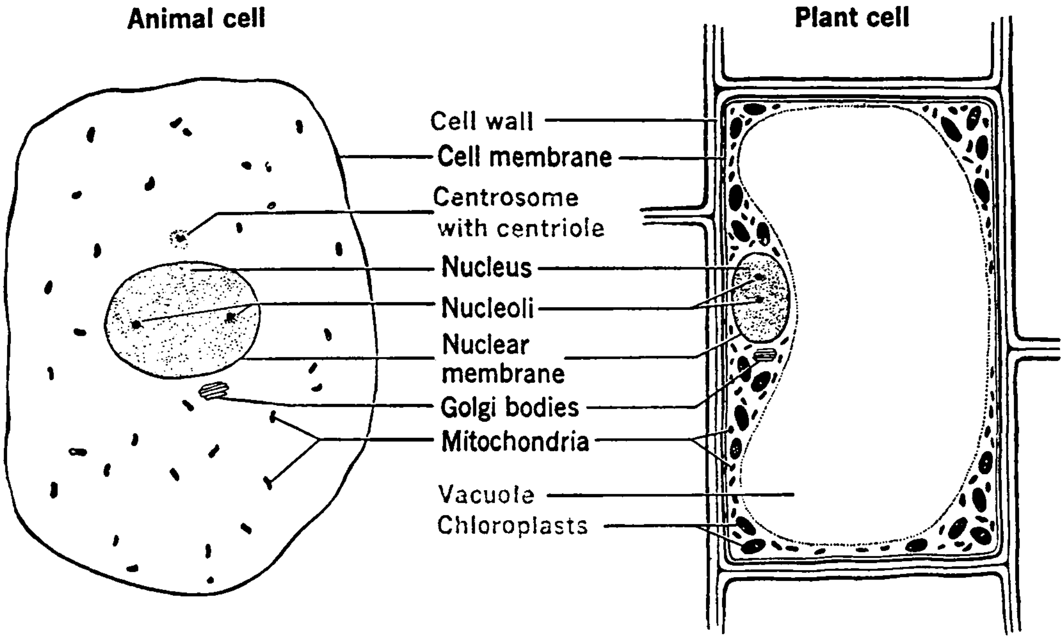

FIG. 2. Eukaryotic cells demonstrate a unity of pattern by means of the many structures they hold in common, but among cells, diversity of type is demonstrable. In the above illustration plant cells display cell walls, a central vacuole, and chloroplasts not seen in the animal cell. In contrast, the animal cell has a centriole in its centrosome, neither of which appears in the plant cell. Beyond these simple diagrams one develops diversity of type during examination of specialized cells such as those of striated muscle and neurons. (BSCS, 1963, p. 58.)

incapable of differentiating between structures that have a superficial resemblance and those displaying more meaningful relationships. In this view of the world, a fish and a porpoise appear far more closely related than a porpoise and a buffalo. Legs are legs. The leg of an insect and that of a cat are locomotor appendages that can be seen to perform the same function for both organisms. Butterflies, bats and birds all have wings and, here again, in the student mind, there must be some relationship among them. It is an interesting assignment to have students pursue these lines of thought. Have them list all the organisms with wings that they can and list all those with legs but without wings on a separate sheet. Other than wings or legs, what do these organisms have in common? Do they form natural groups or do they only possess one prominent characteristic in common?

From such an assignment concepts of homology and analogy can be developed. It becomes readily apparent, for example, that bird wings and insect wings have little structural commonality. The support system of both is different. They are moved differently. A chicken wing, for example, demonstrates some intrinsic musculature. The musculature of a butterfly wing is basically extrinsic. One is covered by feathers, the other by scales. Continuing these comparisons results in a conclusion that this is a relationship of function but not of structure. Similarly, an analysis of an insect leg and a vertebrate one leads to the same conclusion. Exoskeleton versus endoskeleton and muscular placement in relationship to parts of the body are differences that show variations in structure even though the locomotor function is common to both.

The student can be led to an understanding of functional similarities—an understanding that selection has operated several times to produce legs or wings designed for the function of walking or flying—which have come superficially to resemble one another simply because of their selection for a similar function.

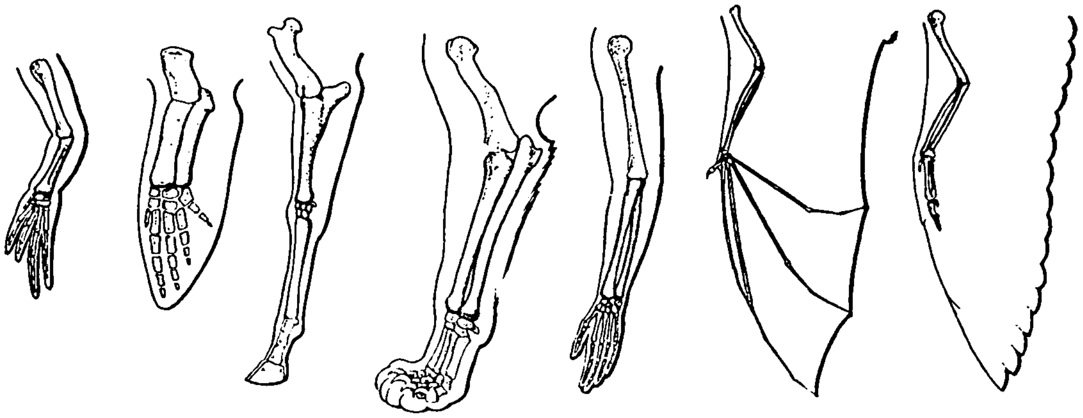

FIG. 3. *Unity of pattern is indicated through this series of forelimbs of seven vertebrates. From left to right,* frog, whale, horse, lion, man, bat and bird. Despite differences of function, each limb has the same basic skeletal structure. The diversity of type arises through the differences in proportion of the skeletal elements in each. Forelimbs, compared to hindlimbs of the same vertebrates, show a serial homology in which the same basic skeletal elements are displayed. (BSCS, 1963, p. 363.)

Among invertebrates, insects display a variety of wing types. Among vertebrates, fossil reptiles, birds and mammals demonstrate flight by means of wings that have more in common with one another than they do with the wings of insects. The principle of analogy involves superficial structural similarities in organs performing a similar function. A student who might have begun thinking that a wing is a wing or a leg a leg wherever it is found, begins to see how natural selection operates to result in the provision of legs as prime terrestrial locomotor organs or wings as a basis for flight through structures that are functionally but not structurally similar.

It is unlikely that students will select wings of bats, birds and extinct reptiles as being closely related in terms of their structure. When presented with a panoply of vertebrate appendages including the flipper of a whale, the leg of a horse, a wing of a bat, and a human arm (Fig. 3), students are, at first, normally incapable of delineating any basic relationships among them. However, closer examination of skeletal elements leads to an appreciation of a basic pattern of resemblance. Students see the same 1:2 pattern in all of the vertebrate limbs they examine. The basic proximal element may be elongated, as in the horse, or compacted, as in the whale, but nonetheless, it is a single element varying primarily in proportion. This is followed by two distal elements, again of varying size but, nonetheless, readily apparent. Further distally comparable bones may be absent or reduced, compacted, as in the whale flipper, or greatly elongated, as in the bat wing. There is, therefore, a basic endoskeletal resemblance in which numbers resulting from fusions and deletions may change as well as proportions, but in which there is a basic structural similarity. This basic structural similarity, coupled with common embryological origin and similar relationship to the parts of the body, as the forelimbs of all vertebrates demonstrate by their relationship to the pectoral girdle, constitutes homology which has been used as an indicator of relationship. It is the study of these homologues that is a central principle within comparative anatomy. The basic patterns demonstrated by homologues illustrate that structures of similar origin may be radically modified to perform special functions. Huxley demonstrated this with the crayfish, showing the modifications possible to a simple, single biramous appendage. The existence of serial homology, resemblance among appendages on adjacent segments, shows on one organism what takes many to demonstrate using different classes and orders.

A study of homologous structures leads to the conclusion that evolution is a conservative process modifying what already exists by changing proportions and positions of previously existing elements in a process of adaptation to a new function. Structures that are greatly reduced are considered vestigial as are the "splint bones" of the leg of the horse. Others have been selected to perform different functions than those originally undertaken. The modification of salivary glands into poison glands in some reptiles, the reorganization and migration of elements of the jaw to form bones of the middle ear, the transformation of sweat glands into milk glands, and the complex relocation of functions of the blood vessels in the transition from gills to lungs are examples of such selection. Thus, basic structural plans demonstrate an adaptability that allows them to be modified by a process of selection to perform functions as diverse as swimming or flying, mastication or hearing. The concept of homology and analogy is a basic principle for a comprehension of form and function as altered by adaptation.

Convergence

Study of homologous structures leads one to begin with a diversity of type and extend it though unity of pattern as organisms become specialized to life in air or water or land. The tendency is to emphasize this divergence but not that the processes of adaptation result in many instances of convergence, in which diversities are reduced. The structural and functional parallelism between families of marsupials and orders of placentals well demonstrates this convergence. Students need understand that the past history of an organism both determines and limits its future directions of structural and functional change. Historical analysis of form is based on the assumption that organisms possess features capable of being ordered into nested sets (a cladogram or phylogenetic tree), and that this pattern reflects a historical process of descent with modification (Fig. 4).

Dollo's Law

Correlated with this assumption is the statement that evolution is irreversible, as encapsulated in Dollo's Law which has become, unfortunately, misunderstood. When we derive from Dollo's Law either the inevitability of progress or a violation of the Second Law of Thermodynamics we have derived nonsense. Dollo's Law is primarily a statement about the statistical improbability of following an identical evolutionary pathway again in either direction. While it is easy to understand the reversal of a single mutation, difficulties are multiplied for larger numbers of mutations, and probabilities become increasingly unlikely for exact repetition of a given evolutionary pathway as the number of genes in a sequence becomes larger. Whales may again return to land, but not by reversing the gene path that led them into the sea in the first place. Their form and function might still be demonstrating unity of pattern, but the diversity of type will follow a different path than that initially taken from land to sea.

The comparative approach

Morphology presented through the structure of a single organism, even while concentrating on it as an example of unity of pattern, does not well explicate diversity of type. The study of human anatomy, for example, concerned primarily with the detailed structure of one organism, may offer only a casual sentence or two concerning the derivation of a structure or its comparison with similar structures in other organisms. The malleus, incus, and stapes of the middle ear are frequently considered as if they were *de novo* mammalian structures without reference to their derivation from jaw bones of lower forms (SAAWOK—I, pp. 32–33). To understand diversity of type and unity of pattern a comparative approach is necessary.

The tendency to select a type organism exemplifying the characteristics of a phylum (hydra, starfish, planarian, clam, crayfish, etc.) tends to emphasize unity, when each organism is considered in isolation, and to ignore diversity. In order that unity of pattern and diversity of type can be incorporated to further an understanding of form and function, animals need be studied as related both in structure and func-

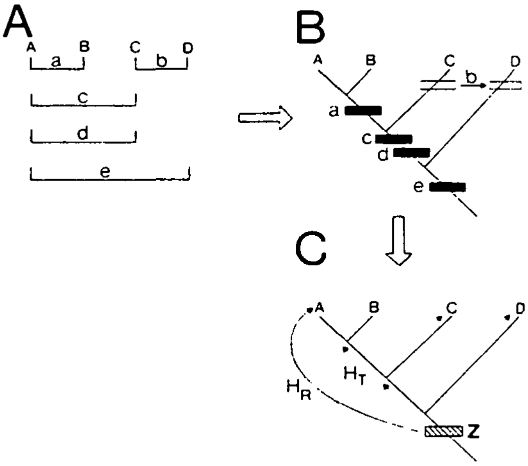

FIG. 4. In order to test hypotheses about the transformation of design, nested sets of similarities (A) are ordered into the most parsimonious cladogram (B). Congruent characters c and d are recognized as homologues for the taxa they define. "b" is the incongruent character and represents a convergence. (C) represents a corroborated cladogram, that is a hypothesis of the phylogenetic relationships of taxa A and D. H_T represents transformational hypotheses, H_R relational hypotheses involving correlations between aspects of the primitive network (Z) and morphological diversity. (Hildebrand *et al.*, 1985, p. 371.)

tion. To speak of chordates, for example, without emphasis on the three characteristics that they have in common (Fig. 5), is to fail to appreciate the unifying structures that relate the members of this phylum (SAAWOK—I, p. 36). While the notochord may be a prominent part of the exposition of the structure of amphioxus, there is doubt that it is homologous to the notochords of vertebrates. Morphological studies of the cat or human may make no mention of the notochord unless embryological development is included, at which time its relation to the vertebral column may be pointed out. But all chordates have a notochord. Even if only fragments may remain in the adult, it nonetheless forms an embryological focus for vertebral column development.

The significance of the presence of a dorsal hollow nerve cord is lost if one studies only human anatomy. Because of the upright human posture and a bipedal stance, the dorsal position of the nerve cord is obscured, and so many other features of the nervous system need be covered that its location as an example of unity of pattern is frequently ignored.

The pharyngeal breathing device (gills or lungs) characteristic of chordates is often misinterpreted. There is ample evidence that this region performs no respiratory function in protochordates where its purpose is filter feeding. Properly gills are found only in vertebrates. Frequently it is stated that presence of gill "slits" sometime in the individual's life history is a chordate characteristic. While pharyngeal pouches or furrows do appear in embryonic development, in birds and mammals they are quite rudimentary, existing only temporarily and normally not perforating to form an actual slit. The presence of a notochord, dorsal hollow nerve cord, and pharyngeal breathing device is a unifying concept describing a chordate pattern. The modifications of these structures provide ample evidence of diversity of type. To emphasize one without the other is to conceal a basic conceptual pattern that should rather reveal relationships and adaptations. This unity of pattern and diversity of type is revealed only through employing a comparative approach to form and function.

Aortic arches

Structure sometimes seems unduly complex and inefficient as in the complex tangle of veins and arteries immediately entering or leaving the heart. To explain to a student what is there does not clarify why the vessel pattern is as observed. The evolution of the aortic arches shows unity of pattern and diversity of type from the primitive condition of six aortic arches through a successive series of losses in an anterior–posterior gradient to mammals (Fig. 6). The first aortic arch is missing in fish. In urodeles, the first and second arches are not present, the fifth is variable. In reptiles, the fourth aortic arch is symetrical. In birds, it persists on the right side only and in mammals it persists on the left side only. SAAWOK—I (pp. 33–35) illuminates these relationships in more detail. The aortic arches illustrate that a comparative approach shows evolution as a basically conservative process, saving from the past what can be used in the present and

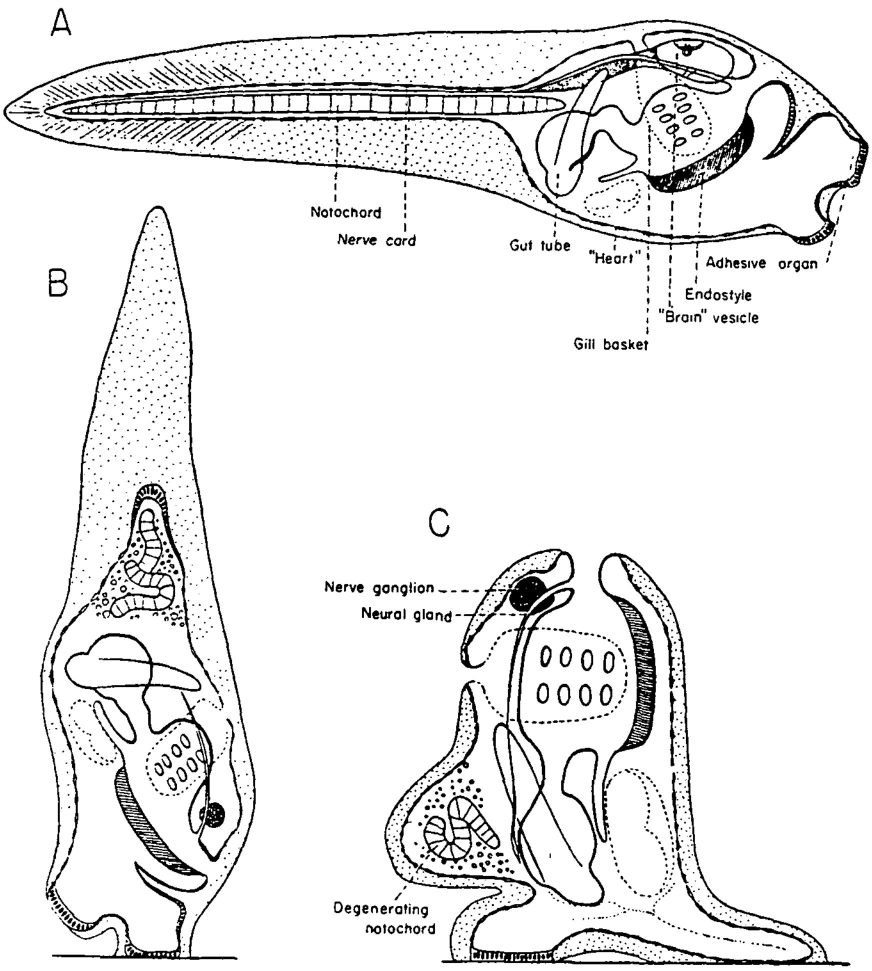

FIG. 5. The free swimming larva (A) of a solitary tunicate displays the notochord, the dorsal hollow nerve cord, and the pharyngeal breathing device characteristic of all chordates. The plasticity of living tissue is illustrated in the metamorphosis of this free swimming larva, which attaches itself to a substrate (B) after which the tail degenerates and most "somatic" structures, except for a notochord remnant, also disappear. In this methamorphosed form (C) the student seldom recognizes that a tunicate is an animal, let alone that it is a chordate. The connection between tunicate and vertebrate through the larva's possession of the three basic chordate characteristics illustrates unity of pattern. The adult demonstrates diversity of type. (Romer, 1962, p. 19.)

modifying a pattern initially designed to supply venous blood to gills. The vessel pattern in an adult mammal is made explicable through knowing the vessel pattern in a fish. Presented as independent systems they seem so at variance, one from another, that no unity of pattern is even looked for. Once a pathway of relationship is shown, however, there is created a unifying pattern to the arterial circulation among organisms as diverse as fish, reptiles, and mammals. The aortic arches constitute a basic unity of pattern capable of being modified into a diversity of types.

It is not lost on students that the appearance of the subclavian and iliac arteries is correlated with the appearance of paired fins. They remain the limb supply through the tetrapod series up to, and including, man whose arms and legs are supplied with blood through subclavian and iliac vessels. Pulmonary arteries make their debut in

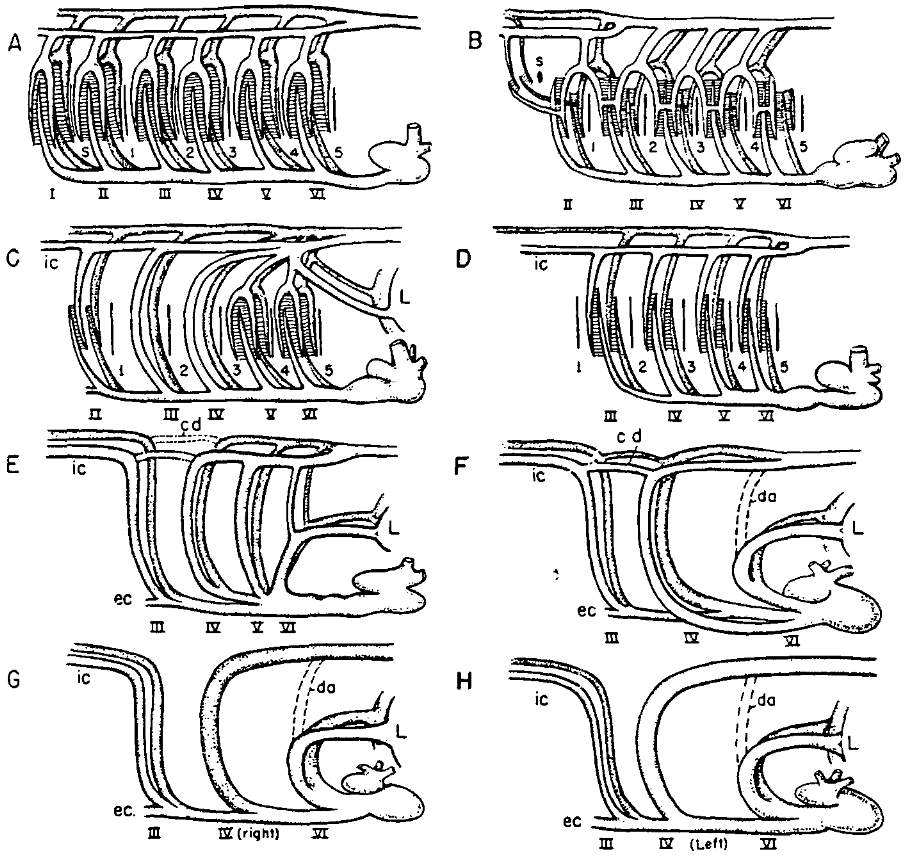

FIG. 6. Unity of pattern and diversity of type, as illustrated by aortic arches and their derived vessels, viewed laterally. A, hypothetical ancestor of jawed vertebrates with six unspecialized aortic arches; B, the typical fish condition illustrated by the shark; C, *Protopterus*, the lung fish; D, a teleost; E, terrestrial salamander; F, lizard; G, bird; H, mammal. The aortic arches are numbered in Roman numerals, the gill slits in Arabic numerals. s, spiracle. cd, carotid duct. da, ductus arteriosus. ec, external carotid artery. ic, internal carotid artery. L, lung. Diversity of type is illustrated by the carotid duct shown in the lizard, which is absent in other reptiles. In turtles, the carotids arise from a separate stem directly from the heart. In the mammal, the embryonic arterial duct, that bypasses the lung, is shown by a broken line. The essentially conservative nature of the evolutionary process is well illustrated by both the ontogeny and phylogeny of the aortic arches. (Romer, 1962, p. 427.)

recent animals in the Dipnoi as branches of the sixth pair of aortic arches. They supply the new lungs emerging from air bladders. This connection of the pulmonary arteries with lungs persists throughout the vertebrate series.

The presence of five pharyngeal pouches and six visceral arches alternating with them in humans reinforces unity of pattern and diversity of type that finds its only reasonable explanation in evolutionary theory. From the pharyngeal region of fish, skeletal elements have been converted into ear bones, attachment for the tongue and support for the larynx. Three of the aortic arches persist and the pharyngeal derivatives of the gill pouches include such endocrine glands as the thyroid, parathyroid, thymus and the ultimobranchial bodies (Fig. 7). From the second pair of pharyngeal pouches come the palatine tonsils, an example of diversity of type most children would prefer not to have to contend with.

The eye

The eye is frequently cited as an organ so complex that the mind boggles when asked to accept that evolutionary processes

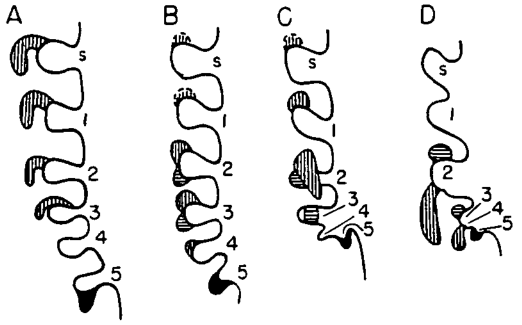

FIG. 7. The gill pouches of the left side of the pharynx in A, shark; B, urodele; C, lizard; D, mammal; s = spiracle, the remaining pouches are numbered. The broken outline indicates variable thymus derivatives; vertical hatching, the thymus; horizontal hatching, the parathyroid; the solid black, the ultimobrachial body. Again, unity of pattern and diversity of type are exemplified, together with the conservative nature of evolution and the plasticity of living tissue. (Romer, 1962, p. 339.)

have led to its present state. By discrediting the ability of complex structures to arise through evolution, anti-evolutionists feel that they are strengthening their case for a designer. The 18th century theologian William Paley first published his *Natural Theology—or Evidences of the Existence and Attributes of the Deity Collected From the Appearances of Nature* in 1802. It is a classic exposition of the argument from design. In it, Paley compares the eye with a telescope and concludes that the eye must have had a designer just as had the telescope. If one were to assume that the eye appeared through natural causes *de novo,* Paley might have a point or even if it developed through a series of smaller steps by random processes. However, the *de novo* eye from natural causes would be as unsubstantiated as is the concept that the eye was created *de novo* by supernatural ones.

One hundred eighty years later, however, Paley's argument appears in the *Neck of the Giraffe* (Hitching, 1982). Except that his book has received a degree of credibility by being published and distributed by a reputable publishing firm, Hitching's thesis is on a par with that in religious tracts of the anti-evolutionists. Hitching makes the error so frequently made by proponents of design when he says "The eye either functions as a whole, or not at all. So how did it come to evolve by slow, steady, infinitesimally small Darwinian improvements?" To amplify his case, Hitching gives as examples that if the cornea is fuzzy (sic), or the pupil fails to dilate, or the lens becomes opaque, or the focusing goes wrong, then a recognizable image is not formed and, therefore, the eye is useless. It is obvious that a fuzzy image is better than no image at all. An image that is too dim, or clouded, or not properly focused, nonetheless, conveys to its possessor an advantage over an organism incapable of perceiving light. Further, Hitching asks "What survival value can there be in an eye that doesn't see?" In the country of the blind, the one-eyed man is king and, among organisms that lack any visual perception, so is an organism that has the ability to distinguish light from dark, or movement, or the fuzzy outlines of a predator. Such an eye, while admittedly not perfect, offers decided survival value.

Hitching makes a case for visual perfection, but almost 50% of the European human population wears glasses or contact lenses. When they are removed, a recognizable image may not form. About one in twelve males is color blind, others are astigmatic. No one with these various visual imperfections would agree that the eye functions either in a state of complete perfection or not at all. Further, the rationale for the all-or-none eye seems to be based on the forging of an absolutely random chain of events, each step apparently starting from ground zero. Instead, evolution is a sequence of gradual step by step changes, each one building on the one before. Any change that improves survival chances is quite likely to be beneficial. Thus, an animal with an eye spot capable of distinguishing between light and dark has an advantage over one that does not possess that ability.

In protists, and throughout the animal kingdom, one finds that sensitivity to light is widespread. An ameba, for example, will not enter strong light. Sea anemones react to light although they have no specialized photoreceptors. All phototropic flagellates have a red pigment spot like that of euglena. In multicellular animals, only those cells respond to light which contain some such pigment as visual purple capable of being

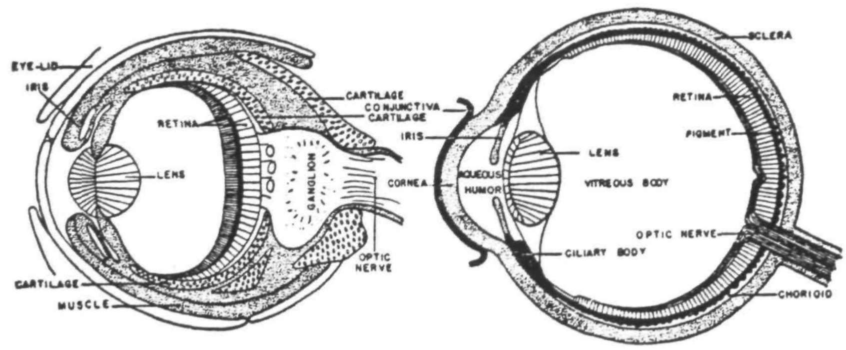

FIG. 8. Median sections through the eyes of a vertebrate and a cuttlefish. In many basics the two eyes resemble one another. However, the retina of the vertebrate eye is inverted, while that of the cuttlefish has the light sensitive cells facing the lens. Light sensitive organs are found throughout the animal kingdom but this parallelism between an invertebrate and vertebrate eye is unique. (Neal and Rand, 1936, p. 581.)

altered by light. The eye spots of coelenterates are pigment cells which respond to changes in light intensity. Many medusae have light sensitive cells on the margin of the umbrella and the jellyfish *Nausithoe* has a lens associated with each of its pigment spots. The pigment spots of many flatworms are light sensitive and, in some species, clusters of pigmented cells surround terminations of sensory nerves.

Even if we regard true vision as limited to animals in which photoreceptors are aggregated into eyes capable of forming an image on a retina, one still sees the formation of eyes independently in a variety of organisms. Some free swimming annelids have "beaker" eyes, so named from their shape, with spherical lenses and a layer of retinal cells connected by nerve fibers with the brain. In some, the beaker-like eyes are associated with the epidermis. In others, the eye sinks below the skin level. *Nereis* worms have a liquid-filled cavity around which photoreceptors are arranged to form a vesicular eye. In mollusks, there are sometimes beaker eyes, sometimes vesicular eyes with a lens. On the edge of the mantle of the pecten are found complex vesicular eyes, each partly surrounded by a layer of opaque pigmented epithelium which, in front of the eye, becomes a translucent cornea. Beneath the cornea and adherent to it is a biconvex lens. The eye of pecten has a retina consisting of two layers of photoreceptors, each connected with a nerve fiber, and the retina is backed with an inner layer of pigmented epithelium. Other mollusks have eyes that are similar to those of vertebrates, particularly *Sepia* and *Loligo.* If anything, the cephalopod eye represents an advancement over that of humans as the retina is not inverted, as in vertebrates, but rather the light sensitive cells face toward the source of light (Fig. 8).

In chordates the retina is derived from the ependymal layer of the neurocoel. Ependymal cells are light sensitive in all chordates from amphioxus to mammals, providing a unity of function within a variety of morphological settings. The paired eyes of all vertebrates are essentially similar. Unity of pattern with little diversity of type. The cyclostome eye and that of a mammal, except for size, are basically the same. The human eye serves as a model for all vertebrate eyes. It is not fair to say that there exists a graded series of light sensitive structures from ameba to man, nor is the claim made for eye spots of euglena and those of planaria being phyletic precursors of the human eye. However, perception of light is a common characteristic of living matter and the variety of light sensitive cells and the functions they perform show a wide diversity of type. What unity there may be is functional rather than morphological. The ability of an ameba to detect light gives it an advantage. The ability of the human eye to form an image gives it a far greater advantage. But between these two extremes are a variety of light sensitive structures which, while they do not form an integrated phyletic sequence, nonetheless serve to illustrate a unity of function if not of structure.

Integumentary system

Practically every organ and system has phylogenetic antecedents that illuminate its structure and function. Perhaps one of the most neglected in the classroom is the integumentary system. The integument provides many examples of unity of pattern and diversity of type. Its position allows it to be observed closely without dissection and on intact, live organisms. Just as one can trace light sensitivity throughout organisms from protists to vertebrates, a covering, separating cytoplasm from the environment, exists in unicellular organisms. A multicellular covering appears in sponges and coelenterates, the latter exemplified by the ectodermal layer of the hydra. Even in such a simple epithelium there is some differentiation. One can see the epithelial covering cells among which are gland cells and some of these, in turn, secrete lime salts. Among other invertebrates the epidermis may be ciliated and the cells also may be involved in secreting an external cuticle. From a simple epithelium to a stratified one, so characteristic of terrestrial organisms, the difference seems to be a change in direction of cleavage planes during cell multiplication.

There are gland cells in a simple epidermis, but in mammals we find a great variety of integumentary glands—sweat glands, sebaceous glands, the lacrimal glands of the eye, the meibomian glands of the eyelids, the wax glands of the auditory meatus, and a variety of others including preputial, vaginal, anal and mammary glands. The luminous organs or photophores of some deep sea fishes are also glandular derivatives complete with condensing lens and a reflecting membrane. Their light is produced by the oxidation of luciferin secreted by the gland with no carbonic acid and little heat evolved in the process.

The presence of finger prints on the palms and soles of all primates are readily observable and well known as sources of identification. The function of these friction ridges is supposedly adhesion—to provide a surface less likely to slip. From the epidermis also are derived the horny scales or scutes of reptiles which are not homologous with the bony dermal scales of fishes (Fig. 9). It should be noted that epidermal derivatives are a product of reciprocal induction. The dermal papilla is a necessary adjunct to structures originating from epidermal cells. Scales persist on the legs of birds and the legs and tails of a variety of mammals such as rodents, insectivores, and marsupials. The Old World pangolin is a mammal that has redeveloped a complete body covering of large horny scales. Bills or beaks are also epidermal structures present in those amniotes in which teeth are reduced or absent. The skin on the jaw margins cornifies to form bills or beaks in birds as well as in turtles and a few mammals such as the monotremes.

Hoofs, nails and claws are other examples of the diversity of type of keratinized epidermal structures (Fig. 10). They tip the digits of amniotes. Horns and horn-like structures are widespread in distribution, particularly among mammals, but many horn-like structures, such as the antlers of deer, are not homologous to the keratin covered bony cores of cattle so that these are functional analogues rather than structures with a unity of pattern. An investigation of the so-called "horns" of mammals shows a wide variety of structures and patterns of shedding from the prong buck, which sheds the horny sheath covering its bony core, to the giraffe whose "horns" are simply bony ossicles permanently covered by skin and hair, or the horn of the rhinoceros, which is but a fused mass of long, modified hairs. The feathers of birds are homologues of epidermal, reptilian scales with a mesodermal component seen during development. Hair is purely epidermal, however. Hairs are not modifications of horny scales and hairs can be considered a mammalian analogue to the avian feather because of their service as an insulating device. In mammals with scales, frequently hairs are found growing between the scales, indicative of the fact that one is not derivative of the other. Integumentary chromatophores account for the varied colors and patterns of animals and play an

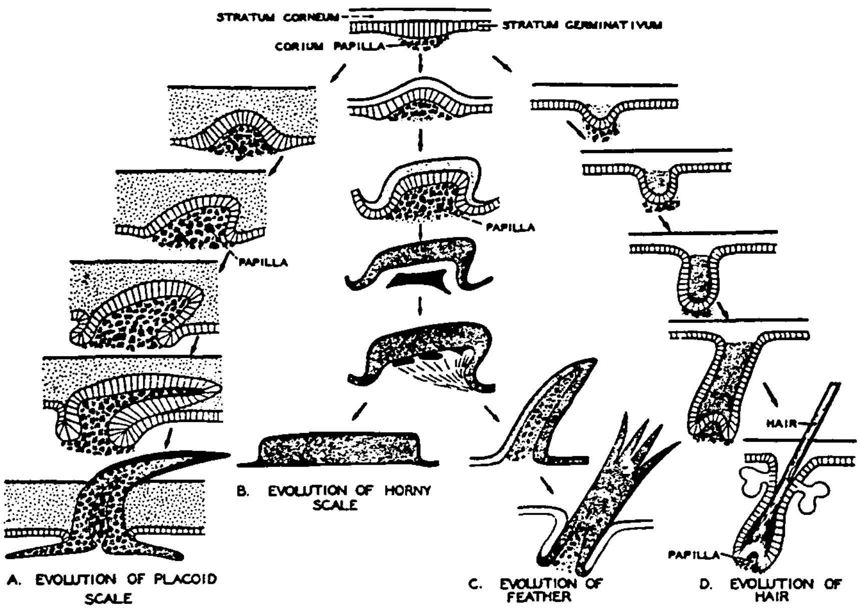

FIG. 9. Hypothetical stages in the phylogenesis of integumentary appendages of vertebrates derived from an undifferentiated epidermis. Unity of type of the placoid scale (A); epidermal (horny) scale (B); feather (C); and hair (D) illustrate the relationships of structures whose functions vary from protection to thermoregulation. (Neal and Rand, 1936, p. 177.)

important role in camouflage, warning, mating and attraction. The color of hair and feathers are mainly responsible for surface coloration in birds and most mammals but in lower vertebrates it is the chromatophores that give the skin its special color.

The wide variety of dermal and epidermal integumentary derivatives provides ample evidence for unity of pattern and diversity of type within the integumentary system. In addition, the integument may play an active physiological role by absorption or elimination of materials through moist skin membranes or glandular structures. The integument functions for breathing in many forms and may also serve as an accessory excretory organ. Embryologically, the nervous system still arises in conjunction with the ectoderm and the skin retains abundant sensory structures, although the vertebrate nervous tissues have primarily withdrawn from the surface.

Too little attention has been given the integumentary system in studies of form and function. It offers a wide variety of adaptive structures and performs a multitude of functions. Both its structure and function are readily observable. It serves to demonstrate unity of pattern and diversity of type and offers both homologous and analogous structures for study.

The digestive system

Unity of pattern and diversity of type is clearly delineated in the study of the digestive system. First, one may divide the functions of the gut as (1) transportation, (2) physical treatment, (3) chemical treatment, and (4) absorption. In organisms above the flatworm level the gut is essentially a hollow tube from mouth to anus. Food is moved along by the muscular contractions of peristalsis which, in turn, may be affected by the autonomic nervous system or by hormones even though the gut muscles operate independently of central control through being stimulated by the contraction of adjacent fibers or through a local nerve net.

Physical treatment. Some animals reduce the size of food taken in through the mouth

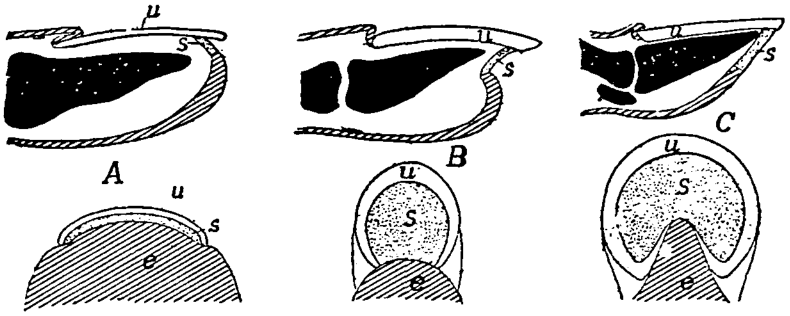

FIG. 10. Epidermal derivatives. (A) nail; (B) claw; (C) hoof; e, unmodified epidermis; u, unguis; s, subunguis. Claws first appear in urodele amphibia and are found in reptiles, birds and mammals. In mammals claws and nails form an integrated series. Hoofs develop on those mammals that run on their toes but the hoof constitutes merely an enlarged and modified claw. In attempting to divide mammals as to whether they are hoofed or clawed, one encounters *Hyrax*, which has both. (Neal and Rand, 1936, p. 172.)

by chewing it into smaller and smaller pieces. Examining the structures for this purpose, the teeth, gives the ability to the biologist who understands Cuvier's dictum of correlation of parts to appear like Sherlock Holmes deducing from meager evidences. From a single fossil tooth, for example, the food preferences of an organism can be deduced and from this, in turn, the type of digestive system, feet, habitat, and behavioral pattern can be correlated with that of a prototype herbivore. Here, unity is brought into play due to the basic patterns held in common by all herbivores. Physical breakdown of food increases the surface to volume ratio and thus facilitates subsequent chemical breakdown. In organisms without the ability to comminute food in the oral cavity, organs such as the gizzard of birds serve as an alternative to mastication. Ingested pebbles serve within the gizzard to facilitate the breaking of food particles into smaller and smaller bits.

Chemical treatment. Water, vitamins, and necessary salts are readily absorbed through the gut wall. Larger molecules such as polysaccharids, fat and proteins require chemical breakdown facilitated by digestive enzymes and accessory secretions that reduce organic materials to molecules that can pass through the cells lining the intestine and enter the circulation.

Absorption. Absorption is a function of time and surface. While in amphioxus and cyclostomes the post-pharyngeal gut is primarily a single tube, most vertebrates have a demarcation between the stomach and intestine in the form of the pylorus (Fig. 11). In those fish in which the pylorus is poorly marked, the bile duct from the liver aids in establishing a line of demarcation. A stomach is absent in amphioxus, cyclostomes and in certain elasmobranchs and teleosts. When present, the stomach serves as a place for storage of food and for its physical treatment as well as its initial chemical treatment, particularly of protein. The absence of a stomach is explicable in the so-called "food strainers" in which food particles are small and collected more or less continuously. They can be passed directly to the intestine without the necessity of either storage or preliminary treatment. This differs from the situation in a shark, for example, in which food intake is only periodic, at which time a large quantity may be taken in so that storage is a necessity until the food can be passed to the intestine. The stomach varies greatly in shape and size among animals and dissection rarely reveals its actual shape after preservation. Incidentally, it needs to be noted that while students are perfectly willing to accept external variation in a species from their own observations, they are frequently incapable of recognizing that similar variations occur internally. The number of times that a laboratory dissection elicits from students that something is "wrong" with their frog or shark because it does not match the pictures and directions in the laboratory manual, confirms that diversity of type as a biological concept has not been internalized. The variety of

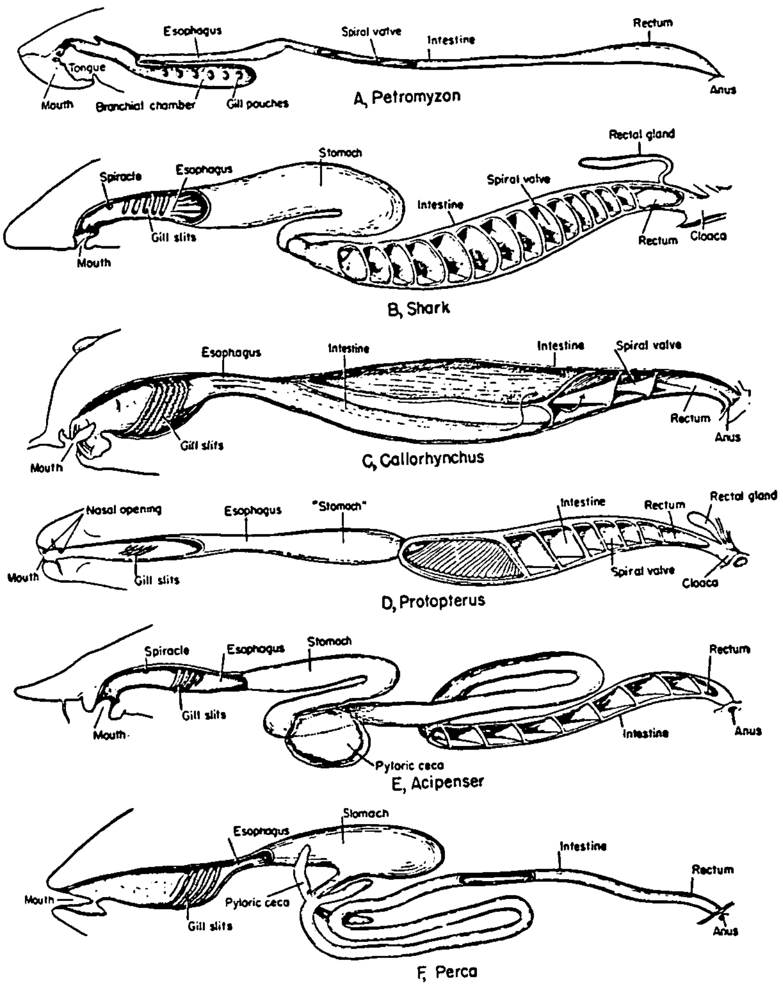

FIG. 11. Digestive tracts of A, lamprey; B, shark; C, chimaera; D, lung fish; E, sturgeon; and F, perch showing diversity of type within unity of pattern. The digestive tract of the lamprey is essentially a straight and only slightly differentiated tube. The spiral valve of the shark greatly increases absorptive surface and a spiral valve is found in the chimaera, lung fish and sturgeon. In the perch, the spiral valve is absent and compensated for by increased intestinal length. The absence of a stomach in chimaera and lung fish is made possible by the feeding habits of both, wherein the food is cut into bits before swallowing, making the need for a stomach as storage area less necessary. (Romer, 1962, p. 347.)

stomachs from non-existent to the specialization of that of the ruminants illustrates unity of pattern and diversity of type while recognizing that the function remains essentially the same regardless of structural adaptation (Fig. 12).

The intestine functions chiefly for absorption which, in turn, is a function of surface area and time. The spiral valve in the intestine of a shark increases surface and slows passage to maximize absorptive capacity and makes meaningless the terms "small" and "large" intestine as applied to mammals and, particularly, to man. The long intestine of herbivores can be contrasted to the relatively short intestine of carnivores. The large functional caecum in such a form as the guinea pig is in contrast to the reduced caecum in such a form as the cat. Accessory organs such as liver and pancreas also vary but functionally they are similar in organisms in which they appear.

One may approach the presentation of the digestive system in terms of its function and show the various patterns designed to facilitate the treatment and absorption of the molecules necessary for continued metabolism. An alternative is to emphasize unity of pattern and diversity of type as facilitating the basic four functions of the digestive system through a series of adaptive patterns that can be utilized to interpret the life style of the organism whose digestive system is being investigated. A simple exercise designed to measure understanding of these correlations is to present students with various gut patterns and ask them to describe structure, habitat and behavior of the organisms in which they would be mostly likely to be found.

References: unity of type/diversity of pattern: Ballard (*1964), Eaton (1960), Hildebrand *et al.* (*1985), Montagna (1959), Murray (1936), Polyak (*1957), Prince (1956), Prosser (*1973), Radinsky (*1987), Romer (*1962), Russell (*1982), Shipman and Bichell (*1985), Wake (*1979).

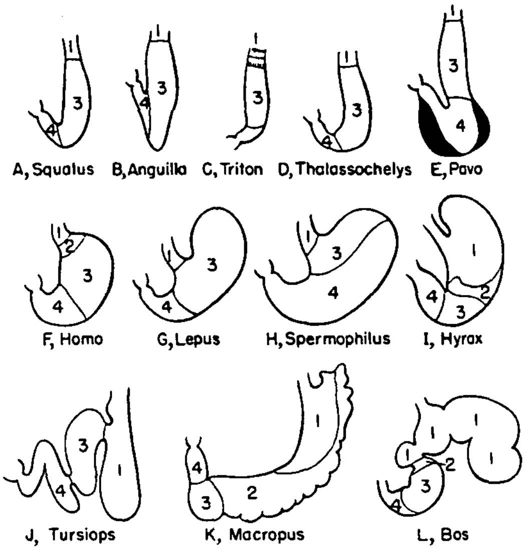

FIG. 12. Stomachs, which serve for storage and digestion, vary greatly among vertebrates. A, shark; B, teleost; C, salamander; D, turtle; E, bird; F, man; G, hare; H, ground squirrel; I, coney; J, whale; K, kangaroo; and L, cow. 1, esophageal epithelium (ciliated in C) which may extend into the stomach particularly in mammals; 2, cardiac epithelium found only in some mammals; 3, fundus epithelium; and 4, pyloric epithelium. The darkened area in the bird represents the thickened wall of the gizzard. Unity of pattern and diversity of type varies throughout the vertebrate series with many specialized mammalian stomach types (F–L). Variation in stomach structure is difficult to ascertain through the dissection of preserved specimens. (Romer, 1962, p. 351.)

CONCLUSIONS

Content of an introductory collegiate biology course constitutes an ad hoc determination by the individual instructor. Even in rare cases where a course outline has been provided by the department, its degree of implementation is erratic and unsupervised. In general, college courses are immune from study and data based recommendations. Prior to 1920 biology programs in secondary schools and introductory courses at the collegiate level were roughly parallel in content and emphasis so that a study of the secondary school of this period is, by inference, a study of the collegiate introductory program. Subsequent to 1920 secondary school programs began to be designed to meet the needs of students and collegiate programs designed to meet the desires of the faculty, even though it is common to find secondary programs still aping those at the collegiate level. Some changes at the secondary school, particularly those of the BSCS, have affected presentations of biology at the collegiate level.

Despite almost a century of studies and recommendations by prestigious committees and commissions the fundamental concepts on which collegiate biology programs can be based are yet to be identified and agreed upon. Few action programs have been implemented and fewer still adopted beyond the boundaries of a single institution. The need for more studies is not indicated, but rather, a need for action relative to already initiated investigations.

The study of form and function has been an integral part of introductory biology since its identification as a discipline. Traditionally, heavy emphasis has been placed on morphological detail and the vocabulary attendant thereunto. The data incident to form and function are usually presented as isolated, unrelated pieces of factual information. The need is for a meaningful synthesis based on unifying principles. The chief of these is unity of pattern and diversity of type, which serves to explicate both relationship and adaptation. Use of the comparative approach and stress on such concepts as analogy and homology, convergence and divergence, and the use of specific systems and structures in such a manner as to illuminate the common threads of structure and function and ways in which they have been modified, serve to make the study of form and function more comprehensible and meaningful.

Improvements in introductory biology courses are not made by the simple substitution of a biochemical terminology for a morphological one to "bring the subject up to date." Rather improvement entails a difference in emphasis, switching from detail to inculcating the ability to analyze, synthesize and evaluate data by use of principles designed to provide a coherent presentation of structure and function. Hurd (1978) looked at future courses for biological education and emphasized the necessity for change. Choices for improvement abound. What is now needed is implementation of selected recommendations within the current framework of courses in colleges.

REFERENCES

Achinstein, Peter. 1968. *Concepts of science.* Johns Hopkins Press, Baltimore.

Armacost, R. and P. Klinge (eds.) 1956. Report of the North Central Conference on biology teaching. The American Biology Teacher 18:4–72.

Ayala, Francisco J. and T. Dobzhansky (eds.) 1974. *Studies in the philosophy of biology.* Macmillan, London.

Baker, Jeffrey J. W. (ed.) 1967. *Biology in a liberal education.* CUEBS Publ. #15. Amer. Inst. Biol. Sci., Washington, D.C.

Ballard, William W. 1964. *Comparative anatomy and embryology.* Ronald Press Co., New York.

Beauchamp, W. L. 1932. Instruction in Science Bulletin 1932, No. 17. National Survey of Secondary Education. Monograph No. 22. Washington, D.C.

Berkheimer, G. D., R. Edmonds, R. W. Hill, L. R. Krupka, H. C. Rudman, and G. A. Smith. 1984. Recommendations for science education. Journal of College Science Teaching xiv:174–180.

Bessey, C. E. 1896. Science and culture. Addresses and Proceedings, National Education Association. Washington, D.C. 35:939–942.

Bigelow, M. A. (chairman) 1906. Committee appointed at the request of the American Society of Zoologists 1906. College entrance option in zoology. School Science and Mathematics 6:63–66.

Biological Sciences Curriculum Study. 1971. The impact of BSCS biology on college curricula. BSCS Newsletter #42:1–8. February.

Blake, Ralph M., C. J. Ducasse, and E. Madden. 1960. *Theories of scientific method.* University of Washington Press, Seattle, Wash.

Braithwaite, Richard B. 1953. *Scientific explanation.* Harper Torchbooks, New York.

Breukelmman, J. and R. Armacost (co-chairmen) 1955. Publications committee 1955. Report of the Southeastern Conference on biology teaching. The American Biology Teacher 17:4–55.

Brody, Baruch A. 1970. *Readings in the philosophy of science.* Prentice Hall, Englewood Cliffs, N.J.

Brown, M. S. and J. L. Goldstein. 1984. How LDL receptors influence cholesterol and atherosclerosis. Scientific American 251:58–66.

BSCS. 1963. *Biological science: An inquiry into life.* Harcourt, Brace and World, New York.

Caldwell, O. W. (chairman) 1920. Reorganization of science in secondary schools. Commission on Reorganization of Secondary Education Bull. 1920, No. 26. Department of Interior, Bureau of Education, Washington, D.C.

Commission on Undergraduate Education in the Biological Sciences. 1967. *Content of core curriculum in biology. Report of the panel on undergraduate major curricula.* Publ. #18. Amer. Inst. Biol. Sci., Washington, D.C.

Conference on Biological Education. 10 March 1953. National Academy of Sciences–National Research Council. (mimeo) Division of Biology and Agriculture, Washington, D.C.

Cox, Donald D. and L. V. Davis. 1972. *The context of biological education: The case for change.* CUEBS Publ. #34. Amer. Inst. Biol. Sci., Washington, D.C.

Creager, Joan G. and D. L. Murray. 1971. *The use of modules in college biology teaching.* CUEBS Publ. #31. Amer. Inst. Biol. Sci., Washington, D.C.

Crosby, C. 1907. Physiology, how and how much. School Science and Mathematics 7:733–744.

Dewey, J. 1916. Method in science teaching. General Science Quarterly 1:3.

Dexter, E. G. 1906. Ten years' influence of the report of the Committee of Ten. The School Review 14:254–269.

Downing, E. R. (chairman) 1931. The teaching of biology. North Central Association Quarterly 5: 395–398.

Eaton, S. B. and M. Konner. 1985. Paleolithic nutrition: A consideration of its nature and current implications. New England Journal of Medicine 31; 312(5):283–289.

Eaton, Theodore W. 1960. *Comparative anatomy of the vertebrates.* 2nd ed. Harper, New York.

Effler, Louis E. 1935. *The eponyms of anatomy.* McManus–Troup Co., Toledo, Ohio.

Field, Ephraim J. and R. J. Harrison. 1957. *Anatomical terms: Their origin and derivation.* 2nd ed. Heffer, Cambridge.

Finley, F. N., J. Stewart, and W. L. Yarroch. 1982.

Teachers' perceptions of important and difficult science content. Science Education 66:631–638.

Fisher, K. M., J. I. Lipson, A. C. Hildebrand, L. Miguel, N. Schoenberg, and N. Porter. 1986. Student misconceptions and teacher assumptions in college biology. Journal of College Science Teaching xv:276–280.

Flaspohler, R. J. and M. D. Swords. 1985. A general education biology course that works. Journal of College Science Teaching xv:117–119.

Gallie, W. B. 1957. What makes a subject scientific? British Journal for the Philosophy of Science 8: 118–139.

Galloway, T. W. (chairman) 1910. Report of the committee on fundamentals of the Central Association of Science and Mathematics Teachers. School Science and Mathematics 10:801–813.

Goodhart, Robert S. and M. E. Shils. 1980. *Modern nutrition in health and disease.* 6th ed. Lea and Febiger, Philadelphia, Pa.

Grobman, Arnold. 1969. *The changing classroom: The role of the Biological Sciences Curriculum Study.* Doubleday, New York.

Hall, E. H. and Committee. 1898. Memorandum concerning report of Committee of Sixty. Addresses and Proceedings, National Education Association, Washington, D.C. 37:964–965.

Hardin, Garrett. 1952. *Biology, its human implications.* W. H. Freeman, San Francisco.

Harre, Romano. 1970. *The principles of scientific thinking.* University of Chicago Press, Chicago. Ill.

Havighurst, R. J. *et al.* 1943. High school science and mathematics in relation to the manpower problem. School Science and Mathematics 43:138–141.

Hildebrand, Milton, D. M. Bramble, K. F. Liem, and D. B. Wake. 1985. *Functional vertebrate morphology.* Belknap, Harvard Univ. Press, Cambridge, Mass.

Hitching, Francis. 1982. *The neck of the giraffe where Darwin went wrong.* Ticknor and Fields, New York.

Hurd, P. De Hart. 1961. *Biological education in American secondary schools 1890–1960.* American Institute of Biological Sciences, Washington, D.C.

Hurd, P. De Hart. 1978. A glimpse into the future. *In* W. V. Mayer (ed.), *Biology teachers handbook,* pp. 565–568. John Wiley, New York.

Huxley, Thomas H. 1880. *The crayfish, an introduction to the study of zoology.* Kegan Paul, Trench, Trubner and Co., London.

International Union of Biological Sciences. Commission for Biological Education. 1987. *A strategy for biology courses for undergraduate non-biology students.* IUBS/CBE, Hamburg, Germany.

Kitcher, Philip. 1982. *Abusing science: The case against creationism.* MIT Press, Cambridge.

Kitcher, Philip. 1984. Good science, bad science, dreadful science and pseudoscience. Journal of College Science Teaching xiv:168–173.

Koballa, Thomas R. Undated. Goals of science education. In *Research within reach: Science education.* National Science Teachers Association, Washington, D.C.

Kockelmans, Joseph J. (ed.) 1968. *Philosophy of science: The historical background.* Free Press, New York.

Kolata, G. 1986. How important is dietary calcium in preventing osteoporosis? Science 233:519–520.

Kuhn, Thomas S. 1970. *The structure of scientific revolutions.* Enlarged ed. University of Chicago Press, Chicago, Ill.

Lawson, Chester A. (Conference director) 1957. Committee on Educatonal Policies, Division of Biology and Agriculture 1957. *Laboratory and field studies in biology: A sourcebook for secondary schools.* Preliminary Edition, National Academy of Sciences–National Research Council, Washington, D.C.

Linn, Marcia C. 1986. Science. *In* Ronna F. Dillon, *Cognition and instruction.* Academic Press, New York.

Linville, H. R. 1910. Old and new ideals in biology teaching. School Science and Mathematics 10: 210–216.

Madden, Edward H. (ed.) 1960. *The structure of scientific thought.* Houghton Mifflin, Boston, Mass.

Maienschein, Jane (ed.) 1986. *Defining biology.* Harvard Univ. Press, Cambridge, Mass.

Margulis, Lynn and K. V. Schwartz. 1982. *Five kingdoms An illustrated guide to the phyla of life on earth.* W. H. Freeman, San Francisco.

Mayer, William V. (ed.) 1978. *Biology teacher's handbook.* 3rd ed. John Wiley, New York.

Mayer, William V. 1986. Biology education in the United States during the twentieth century. Quarterly Rev. of Biology 61:481–507.

Mestre, J. 1987. Why should mathematics and science teachers be interested in cognitive research findings? Academic Connections—Office of Academic Affairs—The College Board. Summer:3–11.

Moll, M. B. and R. D. Allen. 1982. Developing critical thinking skills in biology. Journal of College Science Teaching xii:95–98.

Monmaney, T. 1986. Vitamins: Much ado about milligrams. Science 86, 7(Jan./Feb.):10–11.

Montagna, William. 1959. *Comparative anatomy.* John Wiley, New York.

Moore, J. A. 1988. Understanding nature—Form and function. Amer. Zool. 28:449–584.

Murray, Patrick D. F. 1936. *Bones.* Cambridge University Press, Cambridge.

Nash, Leonard K. 1963. *The nature of the natural sciences.* Little, Brown, Boston, Mass.

National Academy of Sciences–National Research Council. 1955. Division of Biology and Agriculture. Biology Council. Committee on Educational Policies. Proceedings of the Sixth Meeting. 5 September 1955 (mimeo).

National Education Association. U.S. Bureau of Education. 1893. Report of the committee on secondary school studies—Report of the Committee of the Ten. Washington, D.C.

Neal, Herbert V. and H. W. Rand. 1936. *Comparative anatomy.* Blakiston, Philadelphia.

Nightingale, A. F. (chairman) 1899. Report of the committee on college entrance requirements. Addresses and Proceedings, National Education Association, Washington, D.C. 38:625–630.

Nomina anatomica. 1961. Excerpta Medica Foundation, Amsterdam.

Northrop, Filmer S. C. 1947. *The logic of the sciences and humanities.* Macmillan, New York.
Paley, William. 1828. *Natural theology—Or evidences of the existence and attributes of the deity collected from the appearances of nature.* 2nd ed. J. Vincent, Oxford.
Peabody, J. E. (chairman) 1915. Preliminary report of the biology subcommittee on the reorganization of secondary education. National Education Association, School Science and Mathematics 15: 44–53.
Poincaŕe, Henri. 1952. *Science and method.* Dover, New York.
Polyak, Stephen. 1957. *The vertebrate visual system.* University of Chicago Press, Chicago, Ill.
Powers, S. R. (chairman) 1932. A program for teaching science. The Thirty-First Yearbook of the National Society for the Study of Education, Part I. Public School Publishing Co., Bloomington, Ill.
Prince, Jack H. 1956. *Comparative anatomy of the eye.* Thomas, Springfield, Ill.
Prosser, Clifford L. (ed.) 1973. *Comparative animal physiology.* 3rd ed. Saunders, Philadelphia.
Radinsky, Leonard B. 1987. *The evaluation of vertebrate design.* Univ. of Chicago Press, Chicago.
Rechcigl, Milostav, Jr. (ed.) 1977. *CRC handbook series in nutrition and food.* CRC Press, Cleveland, Ohio.
Riddle, O. 1906. What and how much can be done in ecological and physiological zoology in secondary schools. School Science and Mathematics 6:212–216, 247–254.
Riddle, O. (ed.) 1942. The teaching of biology in secondary schools of the United States. Union of American Biological Societies.
Romer, Alfred S. 1962. *The vertebrate body.* Saunders, Philadelphia.
Romer, Alfred S. and T. S. Parsons. 1986. *The vertebrate body.* 6th ed. Saunders, Philadelphia.
Russell, Edward S. 1982. *Form and function a contribution to the history of animal morphology.* Univ. of Chicago Press, Chicago.
Shipman, Pat, A. Walker and D. Bichell. 1985. *The human skeleton.* Harvard Univ. Press, Cambridge, Mass.
Shymansky, J. 1984. BSCS programs: Just how effective were they? Amer. Biol. Teacher 46:54–56.
Simpson, George G. 1976. *The meaning of evolution.* Rev. ed. Yale Univ. Press, New Haven.
Singer, C. 1957. *A short history of anatomy from the Greeks to Harvey.* Dover, N.Y. Reprint of The evolution of anatomy.
Skinner, Henry A. 1961. *The origin of medical terms.* 2nd ed. Williams & Wilkins, Baltimore.
Stanier, Roger Y., E. A. Adelberg, and M. Doudoroff. 1963. *The microbial world.* 3rd ed. Prentice-Hall, Englewood Cliffs, N.J.
Stauffer, Robert C. (ed.) 1949. *Science and civilization.* University of Wisconsin Press, Madison, Wis.
Storer, Tracy I. 1951. *General zoology.* McGraw-Hill, New York.
Suppe, Frederick. 1977. *The structure of scientific theories.* University of Illinois Press, Urbana, Ill.
Suppes, Patrick. 1969. *Studies in the methodology and foundations of science.* Reidel, Dordrecht, Holland.
Supreme Court of the United States. 1987. Edwin W. Edwards, Etc., et al. Appellants v. Don Aguillard et al. No. 85-1513 June 19, 1987. (The decision in the Louisiana "balanced treatment" case.)
Symposium on the function and organization of the biological sciences in education. 1908. School Science and Mathematics 8:536–551.
Thornton, John W. (ed.) 1972. *The laboratory: A place to investigate.* CUEBS Publ. #33. Amer. Inst. Biol. Sci., Washington, D.C.
Tompkins, Peter and C. Bird. 1984. *Secret life of plants.* Harper & Row, New York.
Toulmin, Stephen. 1953. *The philosophy of science: An introduction.* Hutchinson, London.
Tver, David F. and P. Russell. 1981. *Nutrition and health encyclopedia.* Van Nostrand Reinhold Co., New York.
Velikovsky, Immanuel. 1950. *Worlds in collision.* Pocket Books, New York.
Von Daniken, Erich. 1971. *Chariot of the gods.* Bantam Books, New York.
Wain, Harry. 1958. *The story behind the word.* Thomas, Springfield, Ill.
Wake, Marvalee H. (ed.) 1979. *Hyman's comparative vertebrate anatomy.* Univ. of Chicago Press, Chicago.
Wiener, Philip P. (ed.) 1953. *Readings in the philosophy of science.* Scribners, New York.
Woodger, Joseph H. 1937. *The axiomatic method in biology.* Cambridge University Press, Cambridge.