The Biological Sciences Curriculum Study Publications

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Biological science is undergoing a revolution such as physics underwent in the 16th and 17th centuries. Changes and upheavals have altered the perspectives of the subject, even from its position of ten years ago, and it is inevitable that school biology and its textbooks should react sluggishly to these rapid changes. Yet, for several reasons, it is important that boys and girls should be aware of these modern developments. First, simply because they have heard vaguely of DNA or chromosome abnormalities and want to know more, and, second, because the gap is large between the xylem-and-phloem botany or descriptive ecology that is sometimes taught at school and the new work often taught in the universities. A personal example will make this plain. Twelve years ago, when I was a research student at Oxford, the Hill reaction formed part of the experimental work of the last university year. It is now included in the first year course but soon may be elbowed out altogether by newer work. Indeed, a few schools here are demonstrating the Hill reaction in their own sixth form courses. This example shows how courses can change rapidly with increased knowledge, but the argument that school courses should be designed to link up with university courses is a narrow and dangerous one. School courses should be complete in themselves, and the textbooks developed by the Biological Sciences Curriculum Study (BSCS) are based on the assumption that, for most boys and girls, this will be their only formal course in biology. To assist teachers with these courses, BSCS has not attempted to develop a single authoritative program for the study of biology but has prepared a "varied, balanced, and enriched program that may utilize either Yellow, Green, or Blue versions with the possible inclusion of any of a number of Laboratory Blocks, Invitations to Enquiry, and Special Investigations." The BSCS texts—**Biological Science: An Inquiry into Life**. BSCS Yellow version. Textbook and laboratory guide (Harcourt, Brace, and World, New York, 1963. Textbook, 768 pp.; guide, 305 pp. $7.96); **High School Biology** BSCS Green version (Rand McNally, Chicago, 1963. 765 pp. $7.80); and **Biological Science: Molecules to Man**. BSCS Blue version (Houghton Mifflin, Boston, 1963, 872 pp. $7.96)—are accompanied by the **Teachers' Handbook** (Wiley, New York, 1963. 603 pp. $7), edited by Joseph J. Schwab, in which the differences between the three versions are explained. Biology as it rightly says, is not a body of tightly connected, almost axiomatized knowledge, and there is room for differences of view as to what is more and less important in the field. Consequently the emphasis is on the molecular (in the Blue version) and on community and population (in the Green version); the Yellow version gives an up-to-date course in the whole of biology. In general the BSCS texts are very different from conventional textbooks, in which the relative emphasis on the molecular, the community, and the world biome is low. In these new texts it is high. Organ and tissue is stressed in conventional texts but receives little emphasis in the BSCS versions. Despite this variation in treatment, well over half the material is common to all three versions. The stress on up-to-date knowledge is only one aim of the books. The other, and just as important aim, is that of training boys and girls in the methods of science. Thus, in contrast to many standard textbooks, the aims here are to build up arguments to reach a conclusion. The "potted" account of an important observation or experiment is sometimes replaced by the fresh reality of the scientist's own words, and science is not shown as a series of nice, neatly rounded problems with no loose ends or unanswered questions—an important aim when probably one of the gravest dangers of this age is that science might well become a new religion with the scientist as a high priest whose word is unquestionable.

Laboratory work is to be investigative, and not a mere verification of what the book or teacher says. In this intensive program for training in critical thought, an important segment is the *Teachers' Handbook*. Here in the section entitled "Invitations to enquiry," a pupil is shown how to handle and interpret data and how to invent experiments to test hypotheses. If all these aims are achieved, a boy who has gone through such a training should be able to begin to ask the right questions about a given situation. This quality is one of the hallmarks of an educated man and is far more important than remembered knowledge that dates and yellows like last year's newspapers. The laboratory blocks, which provide six weeks of experimental work on a project, give a student the opportunity to tackle a long-term problem. This experience of real investigation will also help train students in the methods of science. The two laboratory blocks that I examined are **Animal Growth and Development** (Heath, Boston, 1963. 93 pp. $1.32), by Florence Moog, and **The Complementarity of Structure and Function** (Heath, Boston, 1963. 90 pp. $1.32) by A. Glenn Richards.

The Blue, Green, and Yellow versions were arrived at in a scientific way. The appearance of the first Russian satellite catalyzed laymen, statesmen, teachers, and scientists into bringing textbooks up to date. The mixture of university and school teachers in particular has brought about the largest and most carefully conducted experiment in biology teaching ever made. The experiment started in the summer of 1960, and the preliminary books produced that summer were tested in 100 schools. As a result of these classroom trials, the material was revised in the summer of 1961. The revised materials were tried out in 500 schools in 1961 and 1962 and in 950 schools the following year.

The above are some of the aims and background of the BSCS books. What in fact do they actually achieve, and what might their use be to the majority of ordinary high school students of 15 and 16 and the teachers for whom they are intended? (It must be remembered that in American

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schools the physics and chemistry courses are normally taken in the two years following that in which biology is studied.)

All the textbooks are impressive with their gay, stout covers that show chromosomes (on the Yellow version), woodland and deer (on the Green version), and, most striking, the pattern of butterfly wing scales and the symbolic representation of the molecular structure of DNA (on the Blue version). The type is clear, the diagrams interesting, bold, and very useful, and the photographs superb. For example, tufts of flagella at the end of a bacillus, the fine structure of a chloroplast, and the shadowy landscape of nucleus, cytoplasm, and virus revealed by the electron miscroscope open up to the student a world as new and exciting as that revealed centuries ago by Galileo's spyglass. Then the photographs—like that of the swarm of Monarch butterflies on a cypress branch in winter or the one of moose drinking—and the paintings—of redwing blackbirds and indigo buntings—show the beauty of the tangible world. All this is very important for the young biologist whose interest can often be aroused by the esthetic appeal of form and color. The observations of the early scientists are not neglected in these books. For instance, Francesco Stellati's sensitive drawings of the bee and Flemming's fine drawings of mitosis in a lily and a salamander are reproduced, among many others, and pictures of Cro-Magnon paintings are given, all adding unusual quality to the books. Then, in the Yellow version, some boys and girls will have pleasure in reading a facsimile of Hooke's vivid description of cork cells, a major advance in man's attempt to understand the basic structure of living things, or in reading Beaumont's clinical report of stomach action which he had carefully observed through a permanent hole in his patient's stomach. If carefully taught, such pieces of scientific history, and there are many in the three versions, can illuminate the difficulties and the imaginative leaps in the process of discovery. Moreover, they give some insight into the thought and motivation of scientists. They can show a student the years of struggle behind the single line in his textbook and put in perspective the importance of modern discovery. They can show the blind path, the faulty argument, the difficulties of technique that beset a scientist, all of which are illustrated in these books. Then again, an able teacher can show that some of the bold questions asked by the Greeks have been asked again and again through the ages and are still unsolved. An apt one described in the Yellow version is the perennial clash between vitalists and mechanists, a debate that is still going on between the holistic and particulate biologists.

The two biologies, "the one holistic, emphasizing function and relationship, seeking an understanding of historical development; the other atomistic, seeking always simpler elements, analyzing by controlled experiment" is part of all the books, but the Green version with its ecological emphasis and the Blue with its molecular approach reach the extremes, while the Yellow version holds the balance. It is impossible to review the subject matter of the books in great detail, but it might be appropriate to consider a few examples of their content in relation to the teaching situation.

Descriptions of photosynthesis are common to all versions, the treatment is historical and follows an argument where evidence is presented. No version is dogmatic (like many textbooks in which conclusions are stated without supporting evidence), and all this is very good indeed. But we are soon into complex biochemistry—electron transfer, ATP, TPN, ribulosediphosphate—that wildly outruns the simple laboratory experiences given in the Yellow and Blue versions (I have not received the Green laboratory manual). One of the major aims of the BSCS was to develop intellectual integrity and a critical attitude to evidence, but it is doubtful whether boys and girls of 15 or 16 would be able to understand or judge the significance of these biochemical theories. Many would be able to memorize the theories, but to exercise a critical judgment on them, which surely is the basis of good craftmanship in science, would be beyond the maturity and scientific background of most. Matters are made worse by the fact that the physics and chemistry courses follow the biology course. The *Teachers' Handbook* gives some excellent summaries on the physics and chemistry underlying biology, but it would require a very able teacher indeed to build these into the biology course, which is full enough in itself. Similar arguments apply to the chapters on the DNA code and RNA. It is good to read such lucid descriptions of the architect and builder of life, but, interesting as it is, it would appear to be outside the understanding of the 15-year-old. To take but one example from the Yellow version:

"You will remember that RNA has much in common with DNA: both are made up of nucleotides. The primary differences are that the sugar of RNA is *ribose* instead of *deoxyribose*, and thymine is not present in RNA. Instead of thymine, we find *uracil* . . . , a pyrimidine very similar to thymine. The two purines and two pyrimidines present in RNA, therefore, are adenine, guanine, cytosine, and uracil."

I doubt whether a fraction of boys and girls would be able to do more than memorize these facts to answer the guide questions and problems that go with each chapter.

It is stimulating to read the chapters on heredity, the chromosome theory, and evolution, for in all versions the argument and the evidence are developed with skill. Mendel's "experiments" are well described, although, in a book preoccupied with scientific methods, the important paper in which R. A. Fisher suggests that Mendel's results were biased in favor of the expected result might have been cited [*Annals of Science* **1**, 115 (1936)]. Mendel probably knew very well what to expect, and his "experiments" were in reality a demonstration of a theory at which he had arrived by an abstract approach not as they are stated in the Yellow version (p. 511). But this is a minor point. Drosophila and maize experiments are suggested to parallel the theoretical work in genetics, but it is a pity that the link between the genetical crossover and its cytological equivalent, the visible chiasma, is not suggested as something that the student can see for himself. This can be done with hybrid *Sordaria fimicola* whose asci contain black and white spores and with chromosomes from the testes of grasshoppers caught in late July. Such laboratory observations are vitally important in bringing the two lines of evidence together, the cytological and the genetical, to make sense to pupils of the chromosome theory of heredity. A dissappointment, in the sections on the mechanisms of evolution, is the lack of emphasis on its study through field, garden, and laboratory observations and experiments. It is true that the story of melanism in moths is described. Just as good is the natural selection of the color forms of *Cepaea nemoralis* by the song thrush which alters from season to season and from place to place, showing that selection is dynamic. The Blue

version gives some guidance to the practical study of variation in the laboratory. But it would be better for pupils to study variation in the field or garden where Bateson said evolution could be seen "rolling out before one" (see *Materials for the Study of Variation*). And what is simpler to investigate than the "staggered" germination and the capacity for marked seed dormancy of common weeds, both insurances for survival, or the ecological niches occupied by closely related species as in the buttercups here. Such observations give real experience of adaptation and survival. Moreover *experience* is being brought closer to that which is being learned, an important teaching point.

The treatment of physiology is considered in all versions under system biology but reaches its extreme in the Blue version. The matter is beautifully arranged and, as far as I can assess, impeccably accurate, but clumsy teaching of system biology can lead to oversimplification, the tendency to make generalizations from too few data, and the neglect of the study of *whole* organisms, living and dead. The Green version encourages this approach through ecology, although the book appears to be very academic for the young whose ecological interests are probably not in tundra or middle latitude deciduous forests but in what they can observe and experience for themselves in New York or Missoula on a mossy wall or under stones or logs in a patch of woodland. But should not the teaching of ecology be a natural part of the teaching of anatomy, taxonomy, evolution, physiology, and other aspects of biology and, as far as possible, closely related to experience in the laboratory? It is to be hoped that any practical work and guidance in the laboratory manual that goes with the Green version will encourage an experimental attitude to ecological problems. School ecology is still largely descriptive in this country, and I suspect it is the same in the United States. A correlation is often made between the distributions of, say, a certain plant and the presence of certain habitat factors, but only experiment will determine which factor or factors control distribution. Of importance here is not only the fun of tackling a real problem and perhaps making a real discovery but the training in the methods of science that simple ecological investigations promote. Simple problems can be found anywhere, not only in woodland or dunes but on waste ground or a wall in a city. If ecology is not taught naturally, with the other parts of the course, it often becomes a section of the teaching to be done quite apart from other aspects of the work in a week at a field station.

The "Invitations to enquiry," in the *Teachers' Handbook* have been mentioned. A series of problem situations, which can be linked to classroom or laboratory work, show a student how to handle data and how to formulate hypotheses and design experiments to test hypotheses. This is excellent, for too often when learning science a student has too little to argue about and discuss. The answers are provided and science seems cut and dried. These "Invitations," with their inductive, deductive, and imaginative facets, should give good training in scientific thinking for the able. What seem to be lacking in the *Handbook* are concrete suggestions on how to teach the main topics —that is, topics like evolution or the chromosome theory of heredity. For example, how do you bridge the gap between firsthand evidence obtained by the pupils themselves and theory? The gap needs bridging by the proper use of secondhand evidence (and some of this is given in the "Invitations"), tables of original data, graphs, films, pieces of original writings, photographs, and models, so that the interplay between first- and secondhand evidence makes a theory such as natural selection appear *reasonable* to the student and is the outcome of solid experience and discussion. For example, in teaching photosynthesis following a period of empirical work in the field, laboratory, and garden, where is the point (if one exists) at which the teacher should introduce Calvin's autoradiographs to show C^{14} tracer distribution in algal cells, obtained after various light periods? Teachers need real guidance on how and when to introduce these data and how to graft the new work onto the classical, and both onto the empirical. The impact of this new work on older teachers whose university courses were finished, say 20 years ago, and whose body of knowledge, as Schwab has written [*BSCS Newsletter* **12**, 12 (1961)], may be largely inadequate and as obsolete as notions "of body humours, the ether or the impenetrable atom," would be to break their backs and perhaps destroy the solid work they are doing in the schools, unless concrete guidance is given through courses in which discussion can take place on how to teach the new work undogmatically. There are dangers in teaching this very recent work, and I will mention one. It has to do with very recent knowledge such as Crick's Theory of DNA coding, so ably described in the texts. The work is enormously fascinating, but it must be remembered that the results are as yet undigested and cannot be seen in their proper perspective. The theory of DNA coding is all the rage and is featured over here in the press and on television, but like all theories it is probably open to severe criticism (which is *not* featured on TV and in the press), and totally different theory may well prove to be correct. I am not suggesting that it is wrong to teach about DNA and DNA coding, but it should not be taught as a proven fact. This is one of the danger points that needs plenty of discussion. Then on quite another plane, one that has nothing to do with modern work but is an important point for teachers to consider, there is the question of experiments by pupils on animals: for example, pithing frogs or removing their pituitary glands or injecting hormones into chicks, suggested in parts of the texts. While I might be considered sentimental by some, there is not only the question of cruelty to animals but that of cruelty to children of *this age* performing the experiments and necessary dissections, which are often done very badly indeed.

To generalize greatly, the level of the texts seems to be pitched too high for the 15-year-old. It is a little surprising that the school teachers on the various committees let some of the text through, but so often a schoolmaster is humbled into silence by a scientist, intellectually quick on the draw, yet the schoolmaster's experience with boys and girls is the touchstone of the ideas being debated.

It has been a great privilege and honor for me as an Englishman to have been asked to review these books, the outcome of the most important experiment in biology teaching ever carried out. Despite the critical nature of this review, there is no doubt that BSCS has provided an inspiration and a challenge to teachers and pupils. Over here we are learning a great deal from the books which will be invaluable sources for years to come; they are making teachers think about what and how they are teaching, engendering an uneasiness that is healthy and creative.