PLANT PHYSIOLOGY IN THE HIGH SCHOOL.

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Ever since the natural sciences began to make their way into the curriculum of secondary schools, discussion as to the character and amount of instruction to be offered in each has formed an important topic in educational meetings and journals. Oftentimes these discussions have shown a strong bias on the part of the advocate of some particular subject, a bias due either to temperament or to special training, or to the nature of the work in which he is engaged. It is difficult for any one to eliminate such bias. It becomes increasingly difficult for one to do so as the field in which his immediate interest lies becomes more and more limited. Therefore the college teacher has oftenest evinced in such discussions a bias leading even to dogmatism. On this account, indeed, teachers in our secondary schools are tempted to discount or to reject without fair consideration the suggestions and advice of university men. I hope, however, that a short personal experience in a city high school, and a somewhat prolonged and intimate acquaintance with high schools of various grades of equipment and the usual limitations as to time, may enable me to write in moderation upon this topic, even though at present it forms the sole subject of my teaching.

It has been conceded generally that botany should have a place in the high-school curriculum, if not as a required subject, at least as an elective with zoölogy. The ease with which material may be secured and preserved, the absence of any repugnance to its handling, and the importance of plant activities in the world's work amply justify its inclusion. For a long time, however, botany was supposed to have as its most important function the acquainting of the pupils with the different kinds of flowers or trees which grew in a limited region. The whole training, therefore, was directed to such a knowledge of anatomy, and particularly of the technical descriptive terms, as would be useful to this end. In all the better schools, however, this limitation of study to the plants of a single group, with a somewhat trivial end in view, has

given way to a more comprehensive study of all the great divisions of plants, to gain the broader and truer conception of the plant kingdom as a whole. In doing this, laboratory work was at first overdone. Latterly, in the wise attempt to regain some features of the valuable training of outdoor naturalists, attention has been given to the relations of plants to the situations in which they grow and to one another, i. e., ecology. For such ecological study a physiological background is most important. But even where ecology has as yet made no way as an elementary subject, the claims of physiology to share with morphology have been pretty generally conceded. The reasons for this are evident enough. What the living being can do is interesting to almost every one, though the trouble necessary to see this is sometimes sufficient to deter the indifferent from the endeavor. But interest becomes awakened when to a knowledge of the structure of plants is added a study of the machinery in action. Physiology, furthermore, gives a kind of training not gained from morphology, and so enriches the whole subject.

If, then, there is a general course in botany, which we may assume to cover at least half a year, and preferably the whole year, what should be the character of that portion of it which is devoted to physiological work? In what relation and proportion should it stand to the other work? What ends should be kept in view?

Before answering these questions I may say by way of introduction that the work should be experimental. No mere study of a book about how plants grow or what they can do will be either interesting or valuable, except to the limited number whose interest in plants is already alive. A book may be necessary (in my judgment it is indispensable) as an accompaniment to the laboratory work, but the experiments themselves should be the main feature and the reading supplementary thereto.

Material for such a course can be grown readily in any greenhouse. Seedlings which can be quickly grown in the laboratory furnish the subjects of many an experiment. A few living plants, which may be derived from window gardens or from commercial greenhouses, will be necessary. One requisite, which in some of the smaller schools is more difficult to secure, is a room that is

not allowed to become cold at nights or on holidays. In such a place, however, if it be impracticable to heat the room from the main furnaces, a baseburner may be provided at small cost, which will obviate the difficulty.

The equipment necessary is also easily obtainable. The few chemicals, tubing, glassware, etc., are already at hand in the chemical or physical laboratory, or can be secured at small cost. In a correspondence course given here, which was more extended than would be suitable for a high school, it was found that the equipment needed for a single student working at home could be supplied for less than \$15. I need hardly say that this would not be multiplied by twenty were a class of twenty working. The apparatus necessary is also limited in amount, and most of it can be constructed by the teacher and pupils at a small cost.¹

I. In an elementary experimental course in plant physiology the study of the most fundamental functions only can be included. The experiments should illustrate how materials get into and out of the plant, a topic which will include the absorption of water and dissolved salts by the roots, of gases (O_2 and CO_2) by the leaves and transpiration. The conditions under which green plants make food should also be determined. Respiration, one of the most widely misunderstood functions of plants, should not be slighted. And finally, growth and movement, being manifested by obvious changes of form or position and readily modifiable by changing the external conditions, should be used to show the sensitiveness of plants and their responses to stimuli. There are a number of books from which experiments on these subjects can readily be selected. These may be modified to suit the conditions of the laboratory in which they are carried out, and will be both illustrative of important facts in plant life and deeply interesting to many students who otherwise would be indifferent.

II. The work in plant physiology may be presented either in connection with the study of morphology or may follow it as an independent division of botany. In my judgment it makes

¹Lists of material and apparatus will be found in the appendix to my *Plant Life*, and admirable suggestions as to material and apparatus for a much more extensive course will be found in Ganong's *Laboratory Course in Plant Physiology*. Both are published by Henry Holt and Company.

little difference which of these two methods is pursued. Both have strong advocates, the former especially being the favorite of those who speak from a theoretical standpoint. It may be pointed out, however, that if one chooses to introduce the study of absorption after a consideration of the structure of the root, and to illustrate transpiration and photosynthesis after the examination of leaves, there can be no serious objection to it, provided certain dangers of omission are guarded against. Too often thus the leaves are left out of consideration as absorbing organs, absorption being associated wholly with the study of the roots. In reality, however, the absorption of gases by the leaves is of quite as much importance as any absorption by roots.

As to the amount of time to be devoted to physiology, it may fairly claim at least one-third, supposing that morphology and ecology share with it; and such a claim would certainly not be unfair if morphology alone were its companion. But no rigid relation of time is necessary or desirable.

III. The purpose of such a course in plant physiology should be primarily to stimulate interest in living things, and to cultivate power of observation; a secondary object should be to illustrate right methods of experimentation and inference. In such an elementary course one danger is to be guarded against most strenuously and continually, namely, the danger of permitting students to imagine that a single experiment, not rigidly quantitative, may be the basis of correct inference. They should be repeatedly warned that such experiments as they are making are merely illustrative of the way in which new knowledge can be gained. The fundamental rule of experimentation must be rigidly adhered to; namely, to have only one variable factor in the experiments. Control experiments under conditions identical except one are indispensable. It behooves the teacher of physiology also to be strictly on guard against the inculcation of bad physics. Much of our physiology, both plant and animal, suffers under this reproach today.

The question is often asked whether the experiments in such courses should be made quantitative. I should reduce the quantitative work in botany to a minimum, for the simple reason that training of this kind can be gained most easily and satis-

factorily in handling material less complicated than living plants. I believe firmly in quantitative experiments in elementary physics and chemistry. In the college or university quantitative work may properly be demanded in the extended courses in plant physiology.

Finally, I may touch the question, in what year of the course should such work be given? I refer to it not to discuss it, but to say that in my judgment it is not worth the time and energy which have been expended upon it. It is clear enough that a *logical* order demands physics and chemistry as a foundation for biology, but it is equally clear that other considerations beside logical order enter into the problem. The teacher who has any capacity for adaptation will be able to handle the botany in the first year or in the fourth. Naturally the two will be quite different in character. If physiology, therefore, comes before courses in physics and chemistry it will be necessary for the teacher to introduce such physical and chemical notions as are indispensable to an understanding of the experiments. This will limit his time and the character of his experiments. But they need not seriously interfere with such a course as I have suggested.

THE FEEDING HABITS OF FISHES.

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There is many a successful teacher of the natural sciences in our high schools who has not had a university training and who may possibly never have had the advantage of advanced work in any department of science, but who is nevertheless keenly alive to the truth of the familiar pedagogical maxim, that to be an inspiring teacher he must keep in touch with the most advanced movements of his subjects. While he cannot sweep the whole field of current research in all of his subjects, he can at least keep abreast of some small specialty and so vitalize his teaching to some degree with the real live blood of scientific progress. If possible he should from time to time contribute something to this specialty himself, some new fact or generalization which may be of value to others.