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THE ELEMENTARY COURSE IN GENETICS¹

THE elementary courses in botany and in zoology have recently been the subject of considerable discussion. One might think that subjects as old and as well established as these which have been taught for many years should long ago have become definitely organized upon the proper pedagogical basis. But these subjects with their various subdivisions have grown so large that it is becoming increasingly difficult to give adequate treatment even in an elementary manner to all phases of either of these two primary biological sciences in the time that is ordinarily available for the beginning course. Teachers of these subjects are, therefore, confronted with the choice of making the beginning course an elementary survey of the entire field of their subject or of boldly eliminating certain phases, leaving their consideration to later and more specialized courses.

Genetics may properly be regarded as one of these subdivisions or phases of biology—a phase of applied biology if you will. But it can not properly be regarded as a phase either of botany or zoology alone, nor can it be adequately treated in a course of instruction by confining one's attention exclusively to one or the other kingdom. The genetics instructor must be free to select his illustrative material from any source, plant or animal, economic or non-economic, as he sees fit. While the greater number of forms of animal life of economic importance are to be found among mammals, birds and fishes, and of plants among the

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angiosperms, certainly much of our collateral evidence in genetics comes from the lower forms of both kingdoms. An adequate treatment of the subject of genetics can not be had under any system of administrative organization which insists upon the drawing of hard and fast departmental lines or in any environment which limits the instructor to the consideration of either wild or domesticated forms of life. In my judgment genetics falls in the same category as cytology and evolution in which the best instruction can not be given without the opportunity of free and unrestricted choice of illustrative material and evidence from both plant and animal life.

Although the science of genetics is by no means as old as that of botany or zoology, its growth and development has been and continues to be of such magnitude that we are rapidly approaching the same state of affairs that confronts the botanist and zoologist. The elements of genetics in all of their details are already extensive and numerous and it is becoming increasingly difficult adequately to treat all phases of the subject even in an elementary way in a single course without making it of unreasonable length. The genetic instructor must, therefore, decide what subject matter is relevant to the object of his course and what is irrelevant and of the former determine what phases may reasonably be left to courses in other biological sciences which may be made prerequisite to the elementary course in genetics and what may well be left for advanced courses in genetics. I confess that the problem of how far to go in the elementary course and what to leave for the advanced course is at times a most perplexing question.

In order to reach the proper decision, we must first define our objective. What is the purpose of the elementary course in genetics? What is its objective? Upon the answer to these questions must our method of procedure necessarily depend. It seems to me that any course worthy of collegiate recognition and standing must be primarily cultural in nature and secondarily informational. It is, however, not impossible to combine these two purposes in any course of instruction even in the professional school, but judging from the array of

courses offered by some departments in some of our agricultural colleges one may wonder if the presentation of encyclopedic information rather than the training of students to do independent and original thinking is not the end attained even though it may not be the objective sought. I wonder if we instructors in agricultural colleges do not sometimes make the mistake of thinking that the agricultural student is not interested in anything that has no direct connection with agricultural phenomena and that it is necessary to sugar coat the pill by giving our courses an agricultural flavor. I admit that we have some students of this type but I believe that they constitute a small minority of the student body, at least at the beginning of their college course. If, however, many of the courses which students find in the agricultural college are largely informational in nature, it is not at all strange that some should regard a modern course in genetics as highly theoretical and of little practical application. When I recall that many of our most successful farmers representing our highest type of rural citizenship are not agricultural college graduates, I wonder if we have perhaps not overemphasized the value of an agricultural course as contrasted to courses in the so-called pure sciences, languages and the humanities even for the man who expects to spend his life and make his living on the farm. I do not underestimate the value of the information he gets in technical agricultural courses but I question if the time that the student is often required to spend in getting this information is proportional to the amount of real and useful information that he gets. One of my colleagues in one of our technical departments recently said to me, "We can give our students all that we know that will actually work on the farm in our field in a three-hour course." Yet I hazard the guess that if you will examine the announcements of courses of departments in this field in our various agricultural colleges, you will find in most of them a relatively large array of detailed courses offered. Where this situation prevails the student is forced to spend an excessive amount of time to get what I am firmly convinced in many cases could be consolidated into much fewer hours if the subject matter

were more concentrated. Furthermore, better teaching would result if courses were designed for the purpose of real mental training rather than for the purpose of giving out a lot of half digested facts, some good, many bad, for absorption by the student to be handed back often in the same undigested form at examinations.

Granting that the primary object of the agricultural college is the training of men and women for farm life, I wonder if we would not be doing that better were we to give in our courses of instruction less consideration to the presentation of information and more to the development of the habit and desire for real thinking. We may well leave the acquisition of some of this information to the student himself if we will acquaint him with the literature of the subject and train him properly to appraise the value of such information as is available and how to use it after he has obtained it.

The teaching of genetics in the agricultural college affords an excellent opportunity for the accomplishment of these aims. If the course is properly organized and presented no student can successfully grasp and assimilate such a body of knowledge without some real mental effort on his part.

I would, therefore, define the objective of the elementary course in genetics as primarily cultural and secondarily informational. If proper consideration be given to its cultural value, it should be of like interest to the student of general biology who expects to go no farther into this field of human knowledge but who desires a general understanding of the phenomena of inheritance, to the student of eugenics and sociology who wants a genetic background for further studies in those fields, to the student who is beginning his special or professional training in genetics or to the student who is specializing in any of the plant or animal industry departments and who desires a genetic training as a basis for plant and animal improvement.

From the informational point of view the general student is not at all interested in a genetic analysis of aleurone color in maize or eye color in *Drosophila*. The same is probably true of the agronomist or animal husbandman. But an understanding of the phenomena

involved in the inheritance of such characters and a knowledge of the mode of attack that has been used in the solution of such problems will be helpful and useful to all and will give to students of applied genetics a better appreciation of the complexity of the mode of inheritance of other characters that are of economic importance and with which as plant and animal breeders they are vitally concerned.

PREREQUISITES

In order to deal with the subject of genetics even in the elementary course in an adequate and satisfactory manner, it is essential that the student have the proper biological background. For the advanced student in genetics a thorough training in either botany or zoology and an elementary training in the other of these sciences is essential but this seems hardly necessary in the beginning course. A sufficient biological training as prerequisite for elementary genetics would seem to be had in a general course in botany or zoology and one in physiology. An elementary knowledge of cytology is, of course, important but the genetics instructor should be able to supplement by lecture or reference without difficulty or without much expense of time such instruction as the student ordinarily gets in cytology in the beginning courses in botany and zoology as may be necessary to an elementary knowledge of the mechanism of heredity.

Certain courses in mathematics are also advisable for the advanced student of genetics but are perhaps not essential for the beginner. The one thing that is essential in my judgment is that the student shall not have forgotten his high school mathematics nor have forgotten how to think and reason in mathematical terms—a condition which too often prevails among students in the agricultural college.

OF WHOM REQUIRED

Of what students in the agricultural college should genetics be required? When I think of my own course I am tempted to answer, of none. I am sure that we would all agree that it is much more satisfactory to work with a class of students all of whom are registered because they want that particular course than because the faculty has ruled that they must

have it before they will be graduated or because some professor has said they must have it before they may take his course. Since I insist upon the privilege of saying that my own students shall have botany or zoology and physiology before they take genetics, I can not well quarrel with a colleague who makes similar requirements of my course as a prerequisite for his.

Perhaps we would all agree that an elementary knowledge of genetics is of value to all agricultural students. But so are courses in many other subjects. If a student were required to have even an elementary knowledge of every thing that is good for him there would be little time left for advanced or specialized courses in any subject. It does seem advisable, however, that as a rule students specializing in any phase of biology should have a course in genetics, though I doubt the advisability of making it a fixed requirement for all. If any group of students should be required to have genetics, it should be those who will later be engaged in the production of better plants and animals and then only in the sense of making it the basis for courses dealing with the application of genetic principles to plant and animal improvement. I am not at all in sympathy with making genetics a requirement for graduation of all students in the agricultural college any more than with making plant or animal breeding such a requirement.

RELATION TO COURSES IN TECHNICAL DEPARTMENTS

Notwithstanding my conviction that the genetics instructor will get better results on the whole if his course is not required, from the standpoint of instruction in the technical departments of plant and animal industry as well as from the standpoint of educational and administrative policy, it would seem important that at least an elementary knowledge of genetics should be made prerequisite to courses in plant and animal breeding if the latter are to be more than a presentation of empirical rules and methods or a consideration of superstitious practices and beliefs. If the genetics course is made prerequisite to such courses the instructor of the latter will have a definite

basis upon which to work and will not be forced to spend his time in a consideration of genetic principles as an introduction to the main part of his course—a tiresome review for those of his students who have previously taken the course in genetics and an inadequate consideration of genetics for those who have not. Time will thus be saved for both instructor and student and better work will be done.

I offer no apologies for the materials of the genetics instructor. Nevertheless, in an agricultural college at least one always encounters a few students of an intensely practical mind, to whom I have already referred, who seem to have little interest in matters not of immediate economic importance or application. Such students one of my colleagues has described as “those who desire information without knowledge.” If left to their own inclinations and desires they are apt to fill up their schedule with what may be termed “informational” courses to the exclusion of courses that require real mental work. It is sometimes possible to command a greater interest on the part of such students by giving careful thought to the choice of illustrative material, by pointing out from time to time some applications of genetic principles in plant and animal improvement and by referring such students to literature illustrating the very practical use of genetic knowledge in the interpretation of phenomena with which they are quite familiar.

SCOPE AND CONTENTS

In my judgment, the elementary course in genetics should constitute a survey of the entire field of heredity. It should be organized and presented in such a manner as to acquaint the student not only with a knowledge of the principles and facts of heredity but of how the science of genetics has been and is being developed, and give him an elementary knowledge of the modes of genetic research. Genetics offers an excellent opportunity for the teacher to present his subject from the research point of view and to demonstrate how human knowledge is advanced. I am inclined to think agricultural students in general get too little of this type of instruction.

Perhaps I can best illustrate the scope and

contents of such a course as I have attempted to describe by briefly outlining our own elementary course in genetics. In doing so, I have no exaggerated idea of the importance of its organization or contents. In fact, we are by no means satisfied with it ourselves and are continually changing it from year to year. Nevertheless, for our conditions, it seems to work fairly well as it now stands. It consists of three lectures and one laboratory period a week for a term of sixteen weeks.

PLANT BREEDING I—GENETICS

1. The methods, problems, scope and relationships of genetics. Relation to evolution, to plant and animal breeding, and to eugenics.
2. Early theories of development and heredity. Preformation and predelineation.—Epigenesis.—Spencer's physiological units.—Darwin's pangenesis.—Naegeli's micellæ.—DeVries' intracellular pangenesis.—Weismann's theory of heredity.
3. The pioneer plant hybridizers. Camerarius' demonstration of sexuality in plants.—The first plant hybrid.—The first extensive series of plant hybridization experiments by Kölreuter, his results and conclusions.—Other early plant hybridizers and their contributions: Thomas Knight and John Goss—the "splitting" of hybrids; Wiegmann and Sageret—the existence of characters in contrasted pairs and the frequent suppression in the hybrid of one parental form by that of the other.—Von Gärtner and his classification of hybrids as intermediate, comingled and decided.—Naudin and his principle of the segregation of species potentialities.
4. Gregor Mendel—the greatest of plant hybridizers. Choice of material.—Methods used and characters studied.—Results in first and second generation hybrids with (a) one character pair, (b) two character pairs.
5. The essential features of Mendel's hypothesis. Independent inheritance of single characters.—Alternative forms of single characters (allelomorphism).—Dominance and recessiveness.—Segregation and the purity of the germ cells.—Recombination.
6. Mendel's methods of testing his hypothesis. Behavior in subsequent generations.—Backcrossing the hybrids to the parental forms.
7. Definition and illustration of Mendelian terms. Gamete, zygote, homozygote, heterozygote, genotype, phenotype, P_1 , F_1 , F_2 , F_3 , etc.
8. Further illustration of Mendelian inheritance and the calculation of Mendelian expectancies. Mono-, di- and trihybrids with and without dominance.—Backcrossing heterozygotes to simple, double and triple recessives.—Algebraic and checkerboard methods of calculation.
9. The mechanism of Mendelian heredity. Brief evidences for the chromosome theory of heredity.—Behavior of the chromosomes in mitosis.—Heterotypic and homotypic divisions.—Parallelism of Mendelian segregation and chromosome segregation.—Chance and probability in inheritance.—Points at which chance is operative.
10. Interaction of factors. Interaction of allelomorphic factors: heterozygous or "unfixable" characters—pink *Mirabilis*, double carnation; homozygous dominant lethal—the yellow mouse, yellow snapdragons, *dichaete* *Drosophila*, etc.—Interaction of non-allelomorphic factors: appearance of new or old characters with normal Mendelian ratios—comb form in fowls, plant color in maize; appearance of new or old characters with modified Mendelian ratios such as 9:3:4, 9:7, 13:3, 27:9:28, 27:37, 27:9:9:3:9:7, etc.—Duplicate and triplicate genes, 15:1 and 63:1 ratios.
11. Sex inheritance and sex determination. The chromosome theory of sex inheritance: cytological evidence; sex-linked inheritance; evidence from parthenogenesis; miscellaneous evidences; attempts at sex control.—Sex inheritance in plants: mosses, ferns and liverworts; dioecious forms among the spermatophytes.—Sex intergrades and gynandromorphs: *Mercurialis*; gypsy moth; *Drosophila*, etc.
12. The physiological basis of sex determination. Hormones of sex glands and their effect upon the development of secondary sexual characters.—Effects of castration and transplation of gonads.—Effects of nutrition.

13. The principle of associative inheritance—linkage.

Discovery by Bateson in sweet peas.—Elaboration by Morgan and others in *Drosophila*.—Extension to other plants and animals by various workers.—The chiasma-type theory as an explanation of the mechanism of linkage and crossing over.—Illustrations of various linkage phenomena.

14. The inheritance of quantitative characters.

The facts.—The interpretations that have been offered.—The multiple factor hypothesis.

15. The statistical study of variation.

Calculation and uses of the ordinary biometrical constants.

16. Correlation.

Calculation and uses of the coefficient of correlation.

17. The pure line concept.

Johannsen's selection experiments and conclusions.—Confirmation and extension by other workers.

18. The role of selection in plant and animal breeding.

Effect of selection in populations of self-fertilized and cross-fertilized plants and with animals under various systems of mating.—Selection from the point of view of the animal breeder.—Modifying factors.

19. Inbreeding and outbreeding.

The conflict of views.—Experimental evidence in both plants and animals.—Interpretation of the results of inbreeding.—Heterosis and its utilization in plant and animal production.

20. Non-Mendelian inheritance.

Cytoplasmic and maternal inheritance.—Chimeras.

21. The mutation concept.

The DeVriesian view.—The modern view.—Point or factor mutations and multiple allelomorphs.—Regional mutations.—Chromosome aberrations.—Bud variations.—Attempts to induce mutations.

22. The mode of evolution from the mutation point of view.

23. Eugenics.

The application of genetic principles to race improvement.—Limitations.

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LAMARCK, MIRBEL AND THE CELL THEORY

It seems to have escaped the notice of writers of text books on biology and the history of science, even in France, that the cell theory in broad outlines was taught in Paris at the very opening of the nineteenth century, forty years before Schleiden and Schwann published their famous epoch-making work.

Lamarck stated clearly in his "Philosophie Zoologique," 1809, that all plants and animals are composed essentially of cellular tissue, without which "no living body would be able to exist nor could have been formed." "Since 1796," he says, "I have been accustomed to set forth these principles in the first lessons of my course."

Lamarck's clear and positive statement of the fundamental importance of cellular tissue, like his theory of evolution, unfortunately was not supported by an array of well authenticated published facts. Lamarck's conception was that cellular tissue (epidermal and connective), enclosing the organism and its parts, is the matrix in which the fluid living matter is shaped into organs, by physico-chemical forces acting upon it from without.

Mirbel, his younger colleague at the museum, adopted the cellular tissue theory, and brought to its support from the field of botany a splendid body of facts, to which long afterwards both Schleiden and Schwann allude. To Mirbel plants are made of a folded membranous cellular tissue, with slow circulation of fluid among the cells through intervening pores.

Dutrochet, in 1824, introduced into the theory the idea of the individuality of the cell, of which all plants and animals are composed; but unfortunately he had no standard by which to decide what is, or what is not, a cell in the animal. The universally present nucleus had not yet been discovered and the cell thus, so to speak, standardized. Hence in matters of detail, he went somewhat astray, but he was a most enthusiastic supporter of the cell theory as he knew it.

Robert Brown, as a by-product of a work on fertilization in Orchids and Milkweeds, described the universal occurrence of cell nuclei.