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Genetics in the Classroom

Programs, Proposals and Experience in Teaching Precollege Genetics

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Drosophila Genetics in the Classroom

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ABSTRACT

Drosophila has long been useful for demonstrating the principles of classical Mendelian genetics in the classroom. In recent years, the organism has also helped students understand biochemical and behavioral genetics. In this connection, this article describes the development of a set of integrated laboratory exercises and descriptive materials—a laborotory module—in biochemical genetics for use by high-school students. The module focuses on the *Adh* gene and its product, the alcohol dehydrogenase enzyme. Among other activities, students using the module get to measure alcohol tolerance and to assay alcohol dehydrogenase activity in *Adh*-negative and -postive flies. To effectively present the module in the classroom, teachers attend a month-long Dissemination Institute in the summer. During this period, they learn about other research activities that can be adapted for classroom use. One such activity that has proved popular with teachers and students utilizes Drosophila to introduce some of the concepts of behavioral genetics to the high-school student. By establishing closer interactions between high-school educators and research scientists, the gulf between the two communities can begin to be bridged. It is anticipated that the result of a closer relationship will be that the excitement and creativity of science will be more effectively conveyed to students.

MANY of us began to work with precollege teachers because we were disturbed by how little the general public—particularly young people—seemed to understand of science. After interacting with students, teachers, principals and superintendents, it became clear to us that most students learn a brand of science that is different than that which with we are familiar. Many learn science history. Some learn science as Latin lessons (THOMAS 1983). A good number take laboratory courses that are little more than cooking exercises. In the main, little is conveyed about the game of science, the curiosity of scientists or the creativity of the scientific process.

Why isn't science being taught in a way that captures its excitement, curiosity and creativity? The answer seems to us that teachers often are far removed from real science. To a considerable extent, the responsibility for this situation lies with the scientific community. Teachers generally have little access to the primary literature. Even if they had, the technical nature of the vocabulary, even in nonspecialist journals, makes it nearly impossible to understand new developments (HAYES 1992). More importantly, the great majority of teachers don't get to interact with practicing scientists. Little communication occurs between the two disciplines. It is because we wanted to foster increased interaction, communication and collaboration that we began our program 7 years ago.

While we have covered many subjects in this time and used more than one kind of experimental material, our major emphasis has been on the use of Drosophila to teach biochemical and, to a lesser extent, behavioral genetics. The rationale for concentrating on biochemical genetics was provided by the observation that while many high-school students study simple Mendelian genetics and molecular biology, most of the students are incapable of integrating the two disciplines. For example, we found that few students (or teachers) could explain what dominant and recessive meant at the molecular level. To help correct this situation, we assembled a group of educators and scientists to help develop teaching materials. In what follows, we offer our experiences to interested researchers in order to help others who have similar aims to avoid some of our mistakes and emulate our successes.

WHY USE DROSOPHILA?

More than 50 years ago two of the leading Drosophila geneticists realized that fruit flies would be ideal organisms for precollege students to use to learn genetics.

> The contributions of the science of genetics with its revelations concerning the mechanism of inheritance represent one of the major developments in the field of biology during the first four decades of the present century. Although during this period the principles of Mendelian inheritance have been clearly defined, and the chromosomal basis of the transmission of hereditary characters definitely established, such fundamental problems as the nature of the gene itself, and the processes it plays in development continue as foci for the concerted study of many present day geneticists.
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> It is our personal experience that there are many intellectually active students who are anxious to initiate steps leading to eventual participation in such a research program, but who lack specific information concerning methods of approach. For some time the Carnegie Institution of Washington has been interested in the possibility of making available certain of the facilities of its Department of Genetics for the use of such students.
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> Various materials, both plant and animal, have been considered as serviceable for an introduction to genetic work, but probably none surpasses the little vinegar fly, *Drosophila melanogaster*, whose study has contributed greatly to the foundations of modern genetics. For the purposes we have outlined here, Drosophila offers the advantage of a short life cycle (about 2 weeks at room temperature) so that numerous generations are procurable in the course of an academic year. Numerous stocks are available by means of which the inheritance of a wide array of visible characters can be studied without the need of any expensive equipment other than a good hand lens or a low power dissection microscope. Despite their small size . . . these flies possess in the salivary glands of their larval stages chromosomes that are among the largest known, and the study of these chromosomes is playing an increasingly important part in the analysis of many current problems.
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> The Department of Genetics of the Carnegie Institution of Washington located at Cold Spring Harbor, Long Island, New York, is prepared to offer, therefore, from its extensive collection of stocks of *Drosophila melanogaster*, a limited number of representative types from which mating may be made to demonstrate the principles of inheritance. First shipments, which will be sent without charge, will include stocks from which monohybrid and dihybrid ratios may be calculated (DEMEREC and KAUFMAN 1940).

After all these years, *Drosophila melanogaster* remains, in fact, a very useful organism for teaching Mendelian genetics. It also serves well for instruction in biochemical, behavioral, molecular and developmental genetics in the secondary schools. Added to the advantages mentioned by DEMEREC and KAUFMAN are those listed below.

- The organism is easy to maintain, relatively cheap to house and safe for humans and the environment. The scientific community has accumulated much experience in its growth and care.
- It has had a very long experimental history that has produced many useful genetic markers and altered chromosomes that facilitate genetic analysis (*e.g.*, balancer chromosomes to restrict recombination between desirable combinations of alleles, and attached-*X* chromosomes to facilitate isolation of *X*-linked mutants). The Mid-America Drosophila Stock Center (Department of Biological Sciences, Bowling Green State University, Bowling Green, Ohio 43403) is a central repository from which thousands of different mutant and wild-type stocks can be obtained at no charge. The National Drosophila Species Resource Center, also at Bowling Green, supplies other species (ca. 300). These cost $20 for the first stock and $2 for each additional stock, with fees waived for people who have no funds.
- Wild-type specimens of *D. melanogaster* can be easily collected in the field, even in urban environments. In many parts of the country, other Drosophila species can be collected so that comparative studies can be carried out.
- It is a relatively complex animal with an interesting developmental program and a sophisticated behavioral repertoire. On the other hand, it is not a vertebrate, and therefore is not subject to the rules and regulations that have been set up for working with such organisms.
- It is small enough so that many individuals can be cultivated in the confines of a high-school laboratory. Yet is large enough so that many features can be easily seen with the naked eye or under weak magnification.
- Finally, the Drosophila research community is a large one. Many colleges and universities have faculty who are familiar with fruit flies and can give advice about their care and feeding to neophytes. Furthermore, Drosophila is the subject of much current experimentation in a great variety of different disciplines, potentially the source of many areas of interest for beginning researchers.

A BIOCHEMICAL GENETICS MODULE

We began by developing a biochemical genetics module—a group of related laboratory exercises and subject matter that cover a limited subset of the curriculum. It contains descriptions of seven laboratory activities that teachers can choose to use in their classrooms over a 1- or 2-week period.

The module focuses on the alcohol dehydrogenase (ADH) enzyme and the *Adh* gene. This gene/enzyme system has played an important role in biochemical, molecular, physiological and population genetics (SOFER and MARTIN 1987). The system was chosen for use in the high-school classroom because ADH activity is particularly abundant in flies, ADH activity is simple to detect and to measure quantitatively, and *Adh*-negative mutants are viable and readily available as are electrophoretic alleles of the gene. In addition, the fact that flies become inebriated and even die in the presence of high concentrations of ethanol piques the interest of many students.

The current version of the laboratory manual consists of several sections. After a few pages that set forth the philosophy of the module, an introductory chapter briefly reviews the history of genetics, biochemistry and the union of the two fields. These first two chapters are intended for teachers. The portion of the module that is of chief concern to students begins with a chapter entitled "Drosophila Manual" that documents such matters as the equipment necessary for raising flies, a description of their life cycle, and methods for culturing, anesthetizing and capturing Drosophila. The Drosophila manual ends with a short section entitled "Troubleshooting" that is intended to address such common concerns as "food drying out" or "white spots on sides of vial."

The bulk of the text covers seven chapters of "Laboratory Activities" including ones titled "ADH and Alcohol Tolerance," "Spot Test for ADH Activity," "Localization of ADH Activity in Drosophila Larval Tissues" and "Introduction to Gel Electrophoresis." Students are taught to use an alcohol tolerance test to tell whether a population of flies exhibits alcohol dehydrogenase activity and to determine what the consequences of lack of activity are, how to measure ADH activity both qualitatively and quantitatively, how to find out where ADH activity is anatomically localized in larvae, how to detect electrophoretic polymorphisms, what it means in biochemical terms for a genetic trait to be dominant, and how biochemical traits are transmitted. The final chapter describes a supplemental activity: the building of an inexpensive electrophoresis chamber and power supply for many of the foregoing experiments.

Accompanying the module is an experimental computer program called "AGenT", written by W. S. and ALAN GERSTEIN. The program is "shareware," with all proceeds from its sale going to Rutgers University. AGenT is a simulation of one of the laboratory exercises in the module. In the program, students are presented with a vial of Drosophila, and they investigate whether the flies carry ADH activity or not. The program is designed to be run by a group of three to six students, one of whom sits at the keyboard and operates the computer. The students are encouraged to explore a virtual laboratory, to open up drawers and cabinets and to try different strategies.

Teachers have made use of the Biochemical Genetics module in a variety of ways. Because of its obvious relationship to alcoholism, some have tied the module to the nature/nurture debate. Others have used used it in the context of bioethics. Those that have been involved in module development or who have attended the Dissemination Institutes (see below) often have used the protocols in the modules to stimulate their students to ask new questions. How resistant to alcohol will a fly be that is the offspring of positive and negative parents? Do other insects have ADH? How will crossing a positive and negative fly affect the electrophoretic mobility of the ADH of their offspring? Students can ask these questions and answer them using the equipment and protocols supplied. One teacher remarked, "Students see science as a dynamic field. Ideas are developed, explored and tested. My students . . . ask if they can do new experiments. I look at their designs and I don't stop them. It's amazing how this approach . . . encourages discovery." In a similar vein, another found that her students ". . . learned to question results" and came to "realize that results do not always agree with theory."

BEHAVIORAL GENETICS: A FUTURE MODULE?

In the summer of 1990 and again in 1991, one of us (L.T.) presented a lecture, video presentation and demonstration on the use of Drosophila to study behavioral genetics to two groups of high-school teachers participating in our program. No attempt was made to develop a behavioral genetics module at the time. However, it was hoped that some of the teachers would be motivated to incorporate observations of Drosophila behavior into their students' laboratory exercises and subsequently provide feedback about their successes and failures, which could lead to the development of a module in the future.

Drosophila larvae and adults will perform many behaviors in a laboratory setting. To enable the participants to become familiar with some of the behaviors that these animals perform, the teachers were provided with reprints and copies of unpublished laboratory protocols that describe simple techniques for observing larval and adult responses to gravity, light, odors and taste stimuli (NAPOLITANO, FORD and TOMPKINS 1986; FORD *et al.* 1989; L. TOMPKINS, unpublished data). They also were given equipment and supplies that they could use to monitor behaviors. The teachers seemed to be particularly interested in Petri dishes that are partitioned into quadrants, which facilitate quantitative observations of larval responses to light and taste stimuli (LILLY and CARLSON 1990). These can be purchased from a scientific supply house for only a few cents more than the plain Petri dishes that are routinely used in high school laboratory exercises.

The lecture and video presentation focused on the use of normal and mutant flies to study adult sexual behaviors, specifically the courtship of virgin females by sexually mature males. The decision to focus on sexual behaviors was deliberate: sex is undeniably a topic of interest to secondary school students, and the responses of male flies to females are complex, dramatic and reproducible, even when viewed with the naked eye. Observations of the sexual behaviors of flies do not require expensive equipment. For example, males will readily perform courtship in the glass or clear plastic vials in which Drosophila are normally housed, although the males will initiate courtship more quickly if they are aspirated into a shallow Plexiglas "observation chamber" (TOMPKINS, HALL and HALL 1980), which also facilitates viewing of the flies through a dissecting microscope or videotaping their behavior. Moreover, using only a stopwatch and a kitchen timer, a student can calculate the percent of the observation period during which a male fly performs courtship (see TOMPKINS, HALL and HALL 1980), the time that elapses before the flies copulate (if ever) and the time that they spend copulating (see TOMPKINS, HALL and HALL 1980). Once they have observed the courtship that genetically normal, sexually mature males perform in response to conspecific virgin females, students have numerous opportunities to be creative: they can observe pairs or groups of flies to observe the effects of varying the environment or one or more of the flies' species, sex, age, genotype and/or state of sexual experience. In addition, students can compare the sexual behaviors that flies perform in a laboratory setting with the behaviors that they perform in their natural environment. From April through Thanksgiving in temperate parts of the United States (year-round in warmer parts of the country), flies will readily engage in courtship in a school yard or a student's back yard, even in an urban environment, if they are provided with a few tablespoons of mashed banana and bakers' yeast in a clear plastic disposable beverage cup through which the flies can be viewed (MCROBERT and TOMPKINS 1986).

The immediate responses of the participants in the Dissemination Institutes to the behavioral genetics presentation were enthusiastic. The teachers asked many questions during and after the lecture and video presentation. Some asked whether the video that they watched had been edited to show only the males that performed the most vigorous courtship (it was not); in general, the teachers seemed to be surprised that the flies routinely engaged in overt sexual behaviors so readily in a laboratory situation. Not surprisingly, since published descriptions of secondary school laboratory exercises in which students observe Drosophila behavior are rare (FORSTER 1974; ROSENTHAL 1979), none of the teachers to whom we spoke had considered the possibility of incorporating Drosophila behavioral genetics exercises into their students' laboratory exercises before participating in the Dissemination Institutes. Some of the teachers said that it would be more feasible to consider incorporating behavioral genetics exercises into their laboratory curricula than exercises involving biochemical or molecular analyses, since little or no expensive equipment was needed for behavioral experiments and a reasonable amount of data could be collected during a single lab period.

It is likely that some of the teachers who participated in the program developed laboratory exercises involving observations of Drosophila behavior, since some of them subsequently requested information about the supplies and equipment used for behavioral analysis. More direct evidence of the impact of the behavioral genetics presentations on secondary students' scientific experiences is provided by the fact that we were subsequently contacted by a participant in the 1990 Dissemination Institute regarding the possibility of his advisee, who was at the time a junior at the United Nations High School in New York City, doing an independent research project in Drosophila behavioral genetics. After talking to the student who was interested in male flies' courtship songs, we designed a research project for her involving the effect of wing mutations on the songs. After visiting L.T.'s lab in Philadelphia to learn how to quantitate females' responses to males' courtship song, the student was able to execute the research project in New York. More recently, a student of one of the program's teachers chose to do an independent research project in which he elucidated the behavioral responses of wild-type larvae to different taste stimuli. Having completed the larval project, the student then expressed an interest in doing a second behavioral genetics project. Accordingly, he visited L.T.'s laboratory to learn one of the basic techniques for analyzing adult flies' responses to taste stimuli, which he is currently utilizing to see whether adult flies' preferences for different stimuli mirror larval preferences for those stimuli.

PRINCIPLES FOR DEVELOPMENT OF MODULES

Over the years, we have come to recognize that modules work best if they are developed according to certain principles.

- In light of our goal of bringing educators and scientists closer together, it is critical that development of the modules should involve both teachers and researchers. The idea is that each group brings its particular talents and expertise to the endeavor. When scientists alone try to develop a module, the result may be more scientifically rigorous, but we found that we regularly betrayed our ignorance of the precollege classroom. For example, we were unaware of the differences among schools in the availability of equipment and supplies. We didn't know that facilities and personnel for maintaining animals over vacation periods were absent in many schools. We didn't know that the length of laboratory periods was different (and often too short) in different schools. We didn't appreciate the time and effort that were required for teachers to set up activities between classes. Of course, teachers are acutely aware of these and other issues. More importantly, they have a deep understanding of individual learning styles, of classroom dynamics and of what will interest groups of teenagers. Imposing teaching materials on teachers without their input is presumptuous and, in the long run, doomed to failure. Involving teachers in module development, on the other hand, helps to build more effective teaching materials and cements the ties between teachers and scientists.

- Modules must be relatively small. What is already being presented in the classroom takes up much of the teacher's time and laboratory schedule. In addition, the small size of modules makes frequent modification possible, in response to new discoveries and new teaching strategies.
- Once a module is developed, teachers must be instructed in its use. Both the scientific background and experimental manipulations must be covered in detail so that teachers feel comfortable in presenting the module in their classrooms. We found that this purpose could best be served by hosting "Dissemination Institutes" lasting 2–4 weeks. At these Institutes, teachers attend classes, meet and talk with members of the scientific community, learn to work with the equipment and organisms that are used in the modules, and discuss strategies for instruction. Dissemination Institutes also offer researchers the opportunity to discuss the challenges of science and to talk about what is unknown and left to be discovered. Ethics, philosophy and careers are also subjects of discussion. We found that many scientists from surrounding universities (in our case, Rutgers, Princeton, University of Pennsylvania, Johns Hopkins University and Temple) were eager to come and exchange ideas on these matters, as well as to talk about their own work. As one can imagine, some scientists were more successful than others in interacting with teachers. Enthusiastic presentation and the ability to communicate without resorting to excessive jargon were two important factors in a successful presentation. These talks were important, too, because teachers could make additional contacts with scientists.
- We found it very helpful to develop ties with another group in the university community—faculty who are specialists in science education. Many universities have a school of education, and among their faculty are some people who are eager to ally themselves with scientists. Faculty in education can help scientists identify appropriate funding agencies, make contact with teachers, schools and school administrators, and familiarize scientists with the pertinent educational literature. In our own particular case, it was GEORGE PALLRAND of the Rutgers Graduate School of Education who initiated the entire project and has helped guide all phases of its development.
- The development of the modules and the running of the Dissemination Institutes required a considerable investment of time and money. The National Science Foundation played a very important part in setting up the Dissemination Institutes and we are very grateful to them. However, they have been less helpful in establishing a mechanism for continuing support for module development and dissemination. To try to compensate for the lack of long-term funding, we solicited the help of industry. Continuing grants from Merck & Co. and support from Hoffman/LaRoche and Schering-Plough have greatly aided our efforts. However, long-term support is still a problem, and it will be especially so for communities that may not have industrial "rich uncles."

WHERE TO ACQUIRE MATERIALS

The Biochemical Genetics laboratory manual can be obtained by writing to S. Coletta at the Waksman Institute, Rutgers University, Piscataway, NJ 08854.

AGenT is available for downloading on the Internet using anonymous ftp from sumex-aim.stanford.edu and from the University of Michigan archives (mac.archive.umich.edu). It runs on a Macintosh II computer with a 13" or greater color monitor. The program may also be obtained from S. Coletta at the address given above.

The biochemical module was developed through a collaborative effort of scientists from the Waksman Institute at Rutgers University and Merck & Co. Inc., and a group of talented high-school teachers. Initial funding was provided by a grant from Merck & Co. During the summer of 1986, W. SOFER, ANDREA MARTIN and PRESLEY MARTIN (at that time a research associate in Sofer's laboratory) began development of the module, assisted by three high-school teachers (L. LUBKIN, A. THOMPSON and A. ZARELLA). In 1987, three new high-school teachers (P. BAER, K. BENSON and P. SIDELSKY) replaced those of the previous year. They further honed the laboratory exercises and rewrote and reorganized the laboratory manual. Dissemination Institutes were held in 1988 and subsequent summers at the Waksman Institute where groups of up to 20 teachers attended for 4-week periods. The current version of the manual contains original artwork by KATHY BENSON and cartoons and illustrations by ANDREA MARTIN.

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