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ABSTRACT

The relationship between classroom work and student understanding of genetics content is examined in this descriptive study of an introductory high school biology class. Classroom observations and examnations of student assignments related to a genetics unit were made. Factors affecting the teacher's management of the work system and the apparent consequences for student learning were explored. Particular attention was given to elements of the system that focused on higher order cognitive skills, that is, work that required application of knowledge to novel situations. Specific questions explored included: (1) how was the genetics content translated into student assignments; (2) how were assignments organized into a classroom work system and how was this system managed; and (3) what were the consequences in terms of learning opportunities for students. A summary is provided of the work systems including consideration of the number and nature of assigned tasks, how time was allocated among classroom activities, and how tasks related to the grading system. A description of the genetics content strands is included. It was found that students experienced difficulties with the genetics content and that explicit instructions along with sufficient novel problem-solving applications appear to be essential for an accurate understanding of genetics. A topic list, task list, and task analysis are appended. (ML)

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Academic Tasks in High School Biology:

A Genetics Unit

This paper presents a descriptive study of academic work in an introductory high school biology class. The class was observed and students' experiences with assignments examined during the teaching of a genetics unit, content which has been identified by high school science teachers as a problem area for secondary students (Stewart, 1982). Factors affecting the teacher's management of the work system and apparent consequences for student learning are discussed. Particular attention is given to elements of the system that included higher order cognitive requirements, that is, work that required organization or application of knowledge to novel situations.

Perspective: Student Work and Understanding of Science Content

Educators typically assume that one of the primary goals of science education is to foster higher levels of cognitive functioning. In science, students are not only to perform, observe, and report, but also to analyze and infer. However, evidence that students actually achieve such levels of cognitive processing is frequently lacking. In the words of the National Commission on Excellence in Education: "Many 17-year-olds do not possess the 'higher order' intellectual skills we should expect of them. Nearly 40% cannot draw inferences from written material . . ." (National Commission on Excellence in Education, 1983).

Some studies suggest that students seldom encounter classwork that requires higher order intellectual processing. In a study of 11 junior high science classes, Mitman, Mergendoller, Packer, and Marchman (1984) noted that only a small proportion of observed tasks required higher level skills. The investigators described 30 of the 31 science laboratory activities observed during the study as low level "observational" or "exploratory" exercises and found the most frequent task type in the classes to be worksheets which, in the majority of instances, required only the copying of answers from resources.

Other studies of academic work in secondary schools suggest that teachers encounter difficulties managing higher order or comprehension level tasks (Doyle, Sanford, French, Emmer, & Clements, 1985; Doyle, Sanford, Nespor, & French, 1985). Doyle and colleagues examined the nature of academic work in secondary classrooms, including science classes, and described interruptions in activity flow and student engagement when higher level tasks (i.e., those requiring students to organize or apply acquired knowledge or skills) were attempted. In addition, extensive teacher prompting or provision of other resources, as well as accountability aspects of the work system, at times reduced or modified the actual cognitive demands placed on students in accomplishing work. In a paper that looked at the impact of teacher management strategies on learning opportunities provided to students, Sanford (1985) discussed the complex and demanding instructional role involved in conducting tasks requiring higher order processing.

Other studies of learning and teaching demonstrate the prevalence of student misconceptions and problem-solving difficulties experienced in relation to science content (Anderson & Smith 1982; Eaton, Anderson, & Smith, 1982; Hackling & Treagust, 1984; Helm & Novak, 1983; Stewart, 1983; Stewart & Dale, 1981). Students in these studies struggled with basic concepts such as those involved in the processes of photosynthesis, respiration, and genetic transmission. The findings of these studies suggest that many elementary and secondary students perform experiments and engage in problem-solving activities without an understanding of either the purpose of the work or concepts and procedures being manipulated. As Novak comments in the overview of the proceedings of the International Seminar on Misconceptions in Science and Mathematics, these students frequently move on the college level where they become, ". . . very clever at hiding their misconceptions by remaining reticent and 'playing the game' which may include verbatim responses to questions or 'algorithmic solutions' to standard text-type problems" (Helm & Novak, 1983).

Concern with student difficulties experienced in relation to science content and the lack of classroom opportunities to develop higher order intellectual skills demands a closer look at the work attempted in science classrooms. A basic premise of the present study is that it is the classroom work system that determines in part what opportunities students are given to manipulate science content and to practice various cognitive operations. This study takes a close look at the relationship between classroom work and student understanding of genetics content in an introductory high school biology class. Before describing the study, a brief review of related studies on the learning of genetics and classroom work is in order.

Research on Teaching and Learning Genetics Content

Genetics content has been rated by high school science teachers as one of the most important, as well as one of the most difficult, biology topics for students to learn (Stewart, 1982). An understanding of the mechanisms of inheritance requires the integration of algorithms and abstract concepts frequently misunderstood by students (Hackling & Treagust, 1984; Stewart, 1983; Stewart & Dale, 1981). Students' learning difficulties have been attributed to a variety of causes, including the abstract nature of the content, lack of explicit instruction on conceptual relationships, and insufficient problem-solving opportunities.

Hackling and Treagust (1984) studied students' understanding of genetics content in introductory high school biology classes in six Western Australian schools. They interviewed 48 students from 13 different science classes, probing for their understanding of 18 propositions identified by lecturers of genetics and secondary school biology teachers as essential for an understanding of the mechanisms of inheritance. In the interviews students were required to apply their understanding of the concepts and propositions in explaining novel situations. Their apparent misconceptions were identified and responses coded as recall or comprehension levels as defined by Bloom (1956). Results showed that close to half of the 18 propositions necessary for an understanding of the content was comprehended by fewer than 25% of the students.

Major difficulties experienced by students in the Hackling and Treagust study included comprehension or application of ideas involved in the separation of chromosome (and gene) pairs at meiosis and their recombination during fertilization. Students also frequently failed to comprehend the role of probability or chance in genetic transmission. The authors attributed these difficulties in part to students' lack of ability to utilize formal reasoning, an interpretation they felt was consistent with research indicating that large proportions of 10th-grade students are limited to concrete operational thought. They made suggestions for demonstrating the abstract meiotic and chromosome recombination processes in a concrete manner utilizing models, but also questioned the suitability of the inclusion of mechanisms of inheritance in the 10th-grade science curriculum.

Stewart and Dale, on the other hand, suggest lack of explicit instruction on conceptual relationships, rather than lack of formal reasoning abilities, as a source of student errors in genetics problem solving (Stewart, 1983; Stewart & Dale, 1981). They conducted interview studies in introductory high school biology classes in midwestern schools. Students were required to solve mono- and dihybrid genetics problems as they explained their reasoning behind manipulations made. The researchers developed and utilized semantic representations to investigate and compare appropriate propositional relationships of the content with student understanding.

Many students in the Stewart and Dale studies were able to execute procedural steps of the problems correctly without demonstrating an understanding of the underlying conceptual knowledge. The investigators identified and distinguished between high and low "meaningful" problem solvers but argued that the two groups did not vary in their "logical" manipulation of the conceptual data. The authors described how both groups of students constructed models of chromosome-allele behavior, used their models to generate hypotheses, and then deduced possible consequences. Differences between the high and low meaningful problem solving groups were noted in the manipulation of erroneous conceptual information, particularly with the segregation and independent assortment of non-homologous chromosome content (difficulties similar to those experienced by students in the Hackling and Treagust study). A lack of problem-solving experience and explicit instruction concerning these conceptual relationships was suggested as a major source of difficulty experienced by students.

In support of their hypothesis, the authors cited the case of a student in one of the studies who had demonstrated initial poor conceptual knowledge of genetics and related problem solving as well as poor performance on a widely used test of intellectual development. This student was tutored for three 40-minute sessions following classroom instruction on the content. The tutoring sessions included practice problem solving and explicit instruction concerning conceptual relationships of relevant concepts. In a final problem-solving interview, this student was able to solve genetics problems successfully, providing accurate information regarding the reasons for manipulations made, thus demonstrating an understanding of the underlying conceptual knowledge and its relationship to the algorithms used.

The problem of integrating algorithms and abstract concepts required for an understanding of the mechanisms of inheritance, along with teachers' concerns about student difficulty experienced in relation to this content, makes the topic of genetics a useful one in attempts to relate student understanding to classroom learning opportunities. Examining the enactment of academic work in science in this light should add new understanding of the complexity and the effects of teachers' decisions about academic work in secondary classrooms.

Research on Classroom Work in Secondary Schools

One source of student difficulty suggested in the Stewart and Dale studies was the lack of problem-solving experience provided by classroom instructional activities. Teachers provide opportunities for students to practice various cognitive operations and skills by assigning work (tasks), which requires students to manipulate or process content in certain ways. Students, then, encounter content in the classroom in the form of assignments. Doyle and colleagues (Doyle, Sanford, French, Emmer, & Clements, 1985; Doyle. Sanford, Nespor, & French, 1985) have examined academic tasks and task systems in secondary classrooms using a framework (Doyle, 1983) in which individual tasks are defined by goal states and classroom events or conditions. This includes: (a) a required end product, (b) conditions and resources (including content instruction) available for accomplishing the work, and (c) inferred cognitive demands in the utilization of resources to produce the end product.

An important variable in Doyle's notion of "task" is accountability. He proposes that students are concerned with what constitutes a correct answer or acceptable product <u>within</u> the evaluation system in place in the classroom. Students' interpretations of and concerns about what the teacher is requiring them to do and how it will be graded play a major role in determining what aspects of tasks students attend to.

In an analysis of teacher management strategies and their effects on the cognitive demands placed on students in accomplishing work in the Doyle studies, Sanford (1985) found that teachers who were able to obtain student engagement in work with potential higher order processing opportunities did so by creating an aura of accountability around the tasks and by providing a variety of "safety-net" devices to keep students from failing. These strategies included (among others):

(a) grading for completion rather than accuracy of products requiring higher level operations; (b) assigning only minor portions of task grades to components requiring higher level operations; (c) allowing students to revise products after receiving extensive teacher feedback with no grade penalty; and (d) allowing students to pool their efforts in groups, at times in the production of a common product.

Sanford noted the importance of student expectations in that serious effort was not likely to be obtained for work that did not contain at least an "aura" of accountability. The <u>routine</u> suspension of accountability or consistent grading for completion rather than accuracy of higher level tasks did not encourage students to attempt comprehension level processing. In addition, some of the safety net strategies tended to reduce teachers' ability to monitor individual student understanding, as in the case of tasks requiring group products. This strategy was also seen in some cases to be a detriment to student understanding, as students shared or confirmed one another's misconceptions concerning the content. In addition, teachers' management strategies frequently reduced the cognitive demands placed on individual students in accomplishing comprehension level tasks.

These studies emphasize the importance of classroom work in students' processing of science content. The implications for student understanding suggest a close look at the intersection of work and student understanding in this area.

Objectives

This paper presents an analysis of the task system in an introductory high school biology class included in the Managing Academic Tasks (MAT) study (Doyle, Sanford, Nespor, & French, 1985). This system is described during the teaching of a genetics unit that included tasks with potential for student practice of higher level intellectual skills (i.e., those involved in the organization or application of knowledge or algorithms in novel situations).

The goal of the study is to elucidate the relationship between the management of classroom work and student understanding of genetics content. Specific questions used to guide the analysis and discussion of this work included:

1. How was the genetics content translated into assignments for students in this class?

2. How were assignments organized into a classroom work system, and how was this system managed by the teacher?

3. What were the apparent consequences in terms of learning opportunities for students and their understanding of genetics content?

METHODS

Sample

The class observed was a first-year biology class taught in an integrated school within a large urban district in the Southwest. The school consisted of grades 9 through 12 and had a student population of 1,128 in the fall of 1984. The class was composed of 1 Indian, 1 Hispanic, 8 Black, and 14 Caucasian students, the majority of whom were ninth- and tenth-graders. The school district had designated the class as an honors section, with a district-mandated curriculum focusing on development of higher level cognitive objectives. The class, however, was composed of a relatively heterogeneous group of students with scores on standardized achievement tests taken from the previous year ranging from the 99th to below the 50th percentile.

The class was taught by an experienced teacher who was department chairperson in the school and a participant in the design of the honors biology curriculum for the district. For the purposes of the study, the teacher had been nominated by both the public school district curriculum coordinator and a university student-teacher coordinator as an effective classroom manager who exposed students to a variety of work experiences, some of which required higher level cognitive processing.

The semester course was entitled, "Plants and Cell Biology," and included the following topics: (a) the chemical nature of life, (b) cellular structure and function, (c) life processes (e.g., photosynthesis and respiration), as well as (d) reproduction and genetic transmission, (e) a survey of microorganisms, (f) the classification and survey of plants, and (g) the structure and function of seed plants. As a part of the honors biology curriculum, students were also required to do an independent research project.

Teacher-listed goals for the course included: (a) exposure to various historical ideas about the origin and nature of life; (b) an understanding of the chemical, structural, and functional nature of living things; (c) the acquisition of knowledge about how traits are passed on from parents to children; (d) the acquisition of knowledge about the structure, reproduction, and importance of plants; and (e) an understanding of relationships between plants and animals; (f) practice in designing, carrying out, and written reporting of independent scientific research projects; and (g) exposure to the area of biology as a consideration in students' future career decisions.

Instructional materials for the course included the 1977 edition of the Modern Biology text (Otto & Towle, 1977); articles and diagrammatic sketches from various magazines and journals including Science, Nature, and the Quarterly Journal of Microscopical Science; filmloops; and teacher-made handouts, overhead transparencies, wall posters, and worksheets.

Data Collection

Data sources included observer notes and audiotape recordings of class sessions, copies of instructional materials, graded student products, and teacher and student interviews.

Observer Notes and Audiotaped Recordings

The class was observed daily during the fall semester of 1984 for an 8-week period including the first week of the school term from 8/27/84 through 8/31/84, and a 7-week period during the teaching of a genetics unit, from 11/12/84 through 12/19/84 and 1/4/85 through 1/9/85. The intervening period, 12/20/84 through 1/3/85, was a school holiday.

Each class session was observed and audiotaped by a trained member of the MAT (Managing Academic Tasks study) research staff with a science education background. The observer kept a running record of the sequence, timing, and content of classroom events and circumstances affecting the work system. These records included descriptions of teacher presentations and student participation with particular attention to information about the nature of assignments, resources available to students, and accountability aspects of the work. Observer notes with audiotaped excerpts were dictated and transcribed into comprehensive narratives immediately following each observation.

Instructional Materials

Pertinent instructional materials regarding the genetics unit were obtained and copied. These included such items as the class textbook and student handouts. Handouts contained information concerning the genetics content including examples or models of work; procedural instructions for laboratory activities; school and class rules, policies, and grading procedures; and course objectives. Handouts included not only content presentations but also worksheets.

Student Products

Whenever possible, graded student products produced during the observation period were collected and copied. The observer typically returned student work to the classroom within a 24-hour period.

Teacher and Student Interviews

The teacher was interviewed by the classroom observer once at the beginning of the school term and again after the completion of the genetics unit on 3/5/85. These were structured, open-ended interviews approximately 1 hour in length. The teacher was asked a number of questions concerning her objectives and planning for the unit, pertinent grading or procedural aspects of the class or work system, perceptions of teaching or learning difficulties peculiar to the content or the class, and the perceived degree of student success on specific tasks.

Nine of the 24 students in the class were also interviewed for approximately 15-to 30-minute sessions at the end of the genetics unit on 1/10/85 and 1/11/85. Students were interviewed by the classroom observer or by another MAT researcher familiar with the class. Both interviewers had science education backgrounds. Interviews were again structured, open-ended exchanges in which students were asked a number of questions concerning their perceptions and understanding of individual tasks, the work system, and the genetics content.

Students were chosen to be interviewed on the basis of varying levels of achievement and work tendencies or patterns, including (a) students who worked relatively independently as well as those who continually requested teacher or peer assistance (some publicly, others privately), (b) students who completed work as well as those who tended not to do so, (c) students who tended to be frequent participators as well as those who were non-participators in classroom discussions and/or group activities, and (d) students who appeared to have specific influences on the task system (e.g., influences on the pace of teacher presentations or classroom events).

Data Analysis

Phase I

Phase I analysis consisted of the identification and detailed description of tasks that were accomplished in the class. Narratives contained information concerning the sequence, timing, and content of classroom events and circumstances affecting the work system. Narrative data, instructional materials, student products, and teacher and student interviews were used to generate:

1. A topic list, consisting of the sequence of classroom events for each session throughout the observation period (see Appendix A).

2. A task list, consisting of a list of individual tasks including brief descriptions or titles, date and time allocations, and product collection dates for each task (see Appendix B). Tasks were identified by the end product of an assignment, for example, a written laboratory report, an oral presentation, or answers on a worksheet or exam paper. Tasks were designated as minor or major tasks according to their

relative contribution to students' term grades. Major tasks constituted 10% or more of the 6-weeks grades.

3. Task analyses, consisting of descriptive, analytical summaries of each task. Appendix C provides an example of an analysis of one major task. The analyses included descriptions of the content covered; relevant teacher presentations; oral or written instructions; date and time allocations including the number of sessions devoted to work involving similar skills or content; prompts, resources, or models available for doing the work; and accountability aspects of the work. Accountability aspects of the work included information concerning the criteria used to grade students' products; how much products counted toward 6-weeks grades; and whether or not students were allowed to re-do, correct, or hand in late work, and what, if any, were the penalties for doing so. They also included descriptions of the sequence and flow of events and circumstances involving the task, including student participation.

Tasks were analyzed in terms of required content manipulation or cognitive demands, both as implied by the teacher descriptions and instructions as well as actual demands made on students after interactions between teacher presentations, student participation including resources used, and accountability aspects of the system had been taken into consideration. Analyses included information concerning content sequencing and pertinent similarities or distinctions from previous tasks as well as teacher and observer perceptions of student success and understanding of the work and content. Any problems observed as the task was enacted in the classroom were discussed.

Phase II

For each task, information concerning content covered, grade weight (i.e., contribution to 6-week term grades), and class time allocations were obtained from individual task analyses and these data were organized into a table with tasks listed by number in order of their completion in the classroom (see Table 1). Tasks were next represented in chart form, again in the order of completion, by specific content covered. Tasks were seen in this chart to contain integrated chunks of genetics content. Two major chunks or content strands were thus identified and mapped through the task system.

Task analyses also provided information for descriptions of each major content strand in terms of: (a) the number, duration, and grade weight of related tasks students completed on that content; (b) how students were required to manipulate that content; (c) resources available for making the required manipulations; and (d) how students were held accountable for manipulations made with the content. Finally, the interaction of the content/resource/accountability aspects of work that addressed each strand of content was considered in making an assessment of the learning opportunities students had in working with that content.

Cognitive demand of the work was a central consideration. We distinguished three levels of cognitive processing: (a) a memorization or recall level, (b) a procedural level, and (c) a comprehension level (see Doyle, 1983). The comprehension level was used to designate opportunities to organize or apply knowledge or skills to novel situations. The procedural level was used to designate opportunities to apply standard routines or algorithms. For example, following a series of computational steps requires more than memorization-level skills. Algorithmic application was only considered a comprehension-level skill when students were required to interpret underlying conceptual knowledge (e.g., when they had to make decisions about selection and sequencing of algorithms).

Student understanding of the content included in each strand was inferred from student participation in the classroom, student products, and interviews. Classroom participation included involvement in whole-class, group, or individual discussions of content. This information was obtained from classroom narratives. Additional information concerning students' understanding of class work and genetics content was obtained from performance on assignments and interview data that contained student descriptions and explanations of what they did during a major experimental laboratory task that involved an integration of inheritance content presented in several tasks.

Student difficulties were identified and discussed in relationship to the management of student assignments.

RESULTS

The analyses described in the previous section resulted in a detailed picture of a system of academic work through which students encountered genetics content in this biology class. The content was organized and introduced to students in a coherent sequence of 26 tasks beginning with those focusing on biochemical and subcellular processes and proceding to work that required the application and integration of inheritance principles and algorithms. Most tasks were short-term although one lab assignment was a long-term task.

The teacher provided students with various resources, including oral and written explanations and demonstrations of required content manipulations in whole-class, group, and individual settings. Major tasks took the form of tests and laboratory assignments.

Many of these assignments included problems that enccuraged students not only to memorize terms or use simple algorithms, but also to demonstrate an understanding of inheritance mechanisms by the application of specific principles. Results also showed, however, that the teacher's decisions about management of accountability for tasks often had the result of mitigating requirements that students demonstrate an understanding of their work.

This section contains a summary of the work system, including consideration of the number and nature of tasks students were assigned, how time was allocated among different classroom activities, and how tasks related to the grading system in this class. This overview is followed by a description of the genetics content as represented by the tasks. Two major content strands are identified and described in terms of task demands (the nature of tasks assigned, the resources students used, what students were held accountable for), and student understanding (what evidence there is regarding what students actually did and what they understood).

An Overview of the Work System

The Tasks

Twenty-six tasks were assigned during the observation period. These tasks are briefly described in Table 1 in the order in which they were completed. Each is described in terms of grade weight (contribution to the 6-week term grade), time allocations, and content covered. All but one of these were relatively short-term tasks, with one to three class sessions devoted to each. The remaining task (Task 22) was a long-term laboratory task involving a fruit fly cross. This task extended over the entire observation period with portions of 17 class sessions devoted to instruction and student work time.

Twenty of the tasks were minor ones in that each constituted less than 4% of the students' 6-week term grades. There were six major tasks including four exams (Tasks 5, 12, 18, and 25) and a lab task, the fruit fly cross (Task 22). These major tasks constituted approximately 11% of students' term grades each while the remaining major task (Task 26) was a final course exam that constituted 50% of their semester grades.

The Task System

Student work was usually introduced by teacher presentations of genetics content and relevant procedures for carrying out laboratory activities. These presentations were instructional episodes in which the teacher explained concepts and demonstrated computational steps to be followed in solving problems, as in the determination of genotypic results of various matings.

The teacher questioned students frequently during these sessions, asking students to repeat information presented and to provide answers to problems as she worked examples on the board or transparencies projected onto a screen at the front of the room. The teacher also reviewed content presented by calling on students to answer questions requiring the utilization of procedures or content presented in previous sessions or work. She then used student answers as starting points for the presentation of new information.

These instructional episodes were at times followed by small group activities that summarized or reviewed the content under discussion. One example of such an activity was group practice in sequentially ordering cards containing representations of cell division stages following a teacher presentation on mitosis. In another instance, students were required to work with partners to summarize the most important ideas presented by Gregor Mendel, following a teacher presentation of Mendel's experimental work with pea plants. The teacher then called on students from each group to provide summary ideas and elaborated on those given.

Each teacher presentation was followed by one to three minor related tasks including homework, quiz, and sometimes laboratory assignments. All homework assignments were short-term tasks to have been completed independently outside of class time. These assignments included worksheets (Tasks 1, 4, 6, 8, and 11) and problem sets (Tasks 15, 16, 19, and 21). Worksheets consisted of a combination of matching, fill-in-the-blank, or short essay questions concerning the genetics content. Students were sometimes required to represent their answers diagrammatically, as in the representation of cells containing pairs of homologous chromosomes (Task 11).

Students were required to work mono- and dihybrid genetics problems (determining geno- and phenotypic results of various crosses), and chi square problems (determining the fit of expected with given experimental results of genetic crosses) for homework problem sets. Although students were expected to do problem sets independently outside of class time, they were required to work in groups of three to four students each during class time to revise their answers before products were collected for grading.

Quizzes were also short-term tasks. These consisted of 1 to 15 fill-in-the-blank, multiple-choice, short essay or problem-solving questions concerning the genetics content. Quizzes tended to be one of two distinct types, those that required students to answer questions concerning the homework reading assignment of the preceding night (Tasks 3 and 20), and those that covered content previously presented and discussed in the class (Tasks 10, 13, 14, and 17). One quiz (Task 7) was a lab practical for which students were required to distinguish the sex of three fruit flies, content discussed by the teacher on 11/2 and covered in a following major laboratory task (Task 22).

With one exception, laboratory work involved short-term assignments. The fruit fly cross (Task 22), however, extended over the entire observation period, with portions of 17 sessions devoted to instruction and student work time. For lab assignments, students were required to make observations concerning various aspects of the genetics content, to record data in sentence, paragraph, or diagrammatic form, and at times to provide written answers to short essay questions concerning observations made or conclusions drawn. For example, one assignment required observation and diagrammatic representation of mitotic stages in onion root tissue (Task 16). Another (Task 24) required the determination of student characteristics concerning various traits (e.g., tongue curling and phenylthiocarbamide taste capabilities). Students were then required to determine their own potential genetic make-up (genotype) for the given characteristics. For one lab (Task 2) students were required to observe and record sex distinctions in fruit flies.

For the long-term lab (Task 22), students were required to set up and carry out monohybrid crosses with fruit flies, crossing a normal (wild type) female with a mutant male. Each lab team of two students was assigned a particular mutant cross, without being told what the inheritance pattern for that mutation was. Observations were to have been recorded and inheritance patterns determined from experimental results. Once students figured out the inheritance pattern for their cross, observed results were to have been analyzed by use of chi square to determine the fit of experimental with expected results and potential sources of error were to have been identified by the students.

Exams were major, short-term tasks composed of from 15 to 113 multiple-choice, fill-in-the-blank, matching, short essay, or problem-solving questions containing genetics content. Three of these exams (Tasks 5, 12, and 18) covered content encountered previously in two to three minor tasks and associated teacher presentations. In addition, a cumulative exam (Task 25) was given at the end of the unit and a final course exam containing some genetics content (Task 26) at the end of the semester course.

Many of the tasks in this class were closely associated with one another in that each required the integration of information presented in previous teacher presentations and tasks. In addition, the major lab task, the fruit fly cross that took place throughout the observation period, required the integration of content presented in a number of instructional episodes and related tasks. A significant portion of tasks in this class also contained comprehension level components to some degree. This included all major tasks (exams and the major fruit fly lab) and at least half of the minor tasks including homework assignments and quizzes.

Accountability for Work

In all but a few instances (Tasks 8 and 23 are the exceptions) student work was checked during class time or collected by the teacher and grades recorded in the teacher's gradebook. Individual student work on problem set homework assignments (Tasks 15, 16, 19, and 21) were followed by small peer group discussion and checking of answers before student products were turned in to the teacher for grading.

The teacher often reviewed content during whole class discussion of answers that served as resources for subsequent tasks such as the unit exam (Task 25). On a number of occasions students were also permitted to modify products following checking episodes or teacher feedback and to resubmit them with no consequent grade penalty.

For most of the problem set homework assignments (Tasks 15, 16, and 19) students were asked to turn in <u>one</u> group product for grading, although each student was to have completed the work. The teacher randomly selected a student's paper from each of the groups for collection and all group members received the same grade given to their member's paper. The teacher checked student work for completion before students conferred in groups, however, and bonus points were given to students whose members had all completed the work. On other tasks completed in small groups (lab assignments), each student received grades on his or her individual product.

The grade weight for individual tasks are given in Table 1. Homework assignments, including worksheets and problem sets together, constituted approximately 12% of students' 6-week term grades (typically less than 2% per task). Quizzes constituted approximately 11% of students' term grades (less than 3% per task).

One laboratory activity and five exams comprised relatively major portions of term grades. Work for the fruit fly cross (Task 22) and four of the major exams (Tasks 5, 12, 18, and 25) constituted approximately 11% of students' 6-week term grades each (a total of 44% of the grade). The final semester exam (Task 26) constituted 50% of students' semester grades.

Genetics Content as Represented by the Task System

Analysis of tasks led to the identification of two major strands of content that were introduced to students through the task system. These included: (a) the structure of nucleic acids and their function in protein synthesis and (b) principles of heredity, including cellular reproduction and inheritance mechanisms.

Content Strand 1 (nucleic acid structure/function) was presented in the task system as it was sequentially organized in the first genetics chapter of Modern Biology, the class text. Strand 2 (principles of heredity) contained an integration of content presented in the following four text chapters, which contained information concerning: (a) cellular growth and reproduction, (b) Mendel's genetic principles of inheritance, (c) application of these principles to chromosome and gene behavior, (d) application of these principles to the inheritance of human characteristics/disease and determination of family pedigrees. Content presented in the last two chapters of the textbook unit on genetics were not included in the task system. These chapters contained information concerning applied genetics (e.g., scientifically controlled hybridization) and evolution.

Each of the two content strands presented in the task system in this class are discussed in the following sections in terms of: (a) task demands, that is, how students were required to manipulate the content and what resources they used in making such manipulations; and (b) student understanding of the content and difficulties encountered in their work. In the final section, we discuss relationships between the teacher's management of the work system and student understanding of the content.

Content Strand 1: The Structure of Nucleic Acids and Their Function in Protein Synthesis

The genetics content was introduced with Strand 1. This included the chemical and physical composition of the genetic material, DNA, and the processes whereby this substance replicates and directs the synthesis of RNA and consequent assemblage of amino acids into proteins. This content included the processes of mutation, replication, transcription, and protein synthesis as well as structural/functional relationships.

Tasks containing content related to Strand 1 included five of the 26 tasks related to the genetics unit. This included major coverage in four of the first five tasks accomplished during the unit: two homework assignments (Tasks 1 and 4) consisting of worksheets over information presented in teacher lectures and textbook readings, one quiz (Task 3) over textbook readings, and one major exam (Task 5) covering all Strand 1 content. This content also received minor coverage in the final semester exam (Task 26).

Strand 1 content was covered in teacher presentations or work on tasks for eight of the 30 class sessions devoted to the genetics unit.

Task Demands for Strand 1

Strand 1 tasks required listings of nucleic acid components, sequencing and diagrammatic representation of replication, translation, and protein synthesis processes, and descriptions of DNA base coding. Students were required to provide or recognize term definitions for three of the five tasks. Definitions could have been copied from textbook pages onto a worksheet for Task 1 (a homework assignment). Students needed to utilize recall level operations to recognize definitions given for terms in multiple-choice test items for Tasks 5 and 26.

Task 5 (an exam) also required students to recognize descriptions of nucleic acid differences and similarities. For example, this task included the following set of matching questions:

A. DNA only
B. RNA only
C. Both DNA and RNA
D. Neither DNA nor RNA

1. Made of nucleotides
2. Contains uracil (U)
3. Used by the cell to produce energy
4. Contains the sugar deoxyribose
5. Inherited directly from your parents
6. Double stranded
7. Able to replicate
8. Produced by a cell when a specific protein is needed
9. Contains guanine (G)

This question required the recognition of structural and functional aspects of both DNA and RNA. Each of these aspects had been presented in text pages and/or teacher lectures previous to Task 5. The teacher also reviewed this content by asking for oral student responses to a number of questions similar to these immediately before students began work on the task.

Students were required to provide short-essay descriptions of: (a) the role of cellular structures (ribosomes) in protein synthesis for Task 3 (a quiz), and (b) the significance of protein synthesis for Task 1 (a homework assignment). Similar descriptions were given during teacher presentations and students were allowed to copy information from notes taken during presentations onto quiz papers.

Students were required to translate (or recognize translations of) diagrammatic representations of DNA segments into replication/transcription/protein synthesis products for four of the five tasks. For Task 1 this was a simple requirement that involved the mere matching of letters as in the following example:

> If one strand of a double-stranded DNA reads, A-T-T-G-A-C-T-C-G, write in what the sister strand would read.

Students needed to match C's with G's and A's with T's to form the "sister strand." Again, the pairing information could have been obtained from text pages and then numbers listed in sequence on the worksheet. Both Tasks 5 and 26 contained similar questions in the form of multiple-choice test items.

Tasks 1 and 5 also required students to provide short-essay and/or diagrammatic representations of entire processes rather than the mere recognition or provision of end products. For example, Task 5 included the following question:

"Show or tell with words and/or diagrams, how DNA replicates." Students needed to provide some description or representation of the composition and separation of DNA strands and consequent joining of free-floating nucleotide bases for these questions. For the homework assignment, students could have copied either the two-sentence description or diagrammatic representation from text pages. Although students could have utilized recall level operations to reproduce these descriptions for the exam, the text diagram was somewhat complex, with 66 separate segments representing nucleotide bases. Students would have needed to utilize extensive recall operations without a diagram to copy from. Therefore, this task was likely to require some interpretation of the replication process as presented in text pages or teacher descriptions if students chose to give diagrammatic representations.

Task 4 (a homework assignment) required the diagrammatic translation of a DNA segment into first replication, then transcription and protein synthesis products. This task also required more than the pairing of letters representing nucleotide bases. Part of the task read as follows:

> Assume that the following sequence of bases composed one strand of a DNA molecule: C-A-C-G-T-T. What sequence of bases would the partner strand contain? If this strand of DNA produced messenger RNA, what sequence of bases would be found in the messenger RNA? How many transfer RNA's could attach to this small mRNA? What would their sequence be? Use the chart on page 82 of your text book. What two amino acids are coded for? (Hint: The triplet codes listed are the bases for the messenger RNA for each amino acid, use the first one listed.)

For the first part of this task students needed to know that C's match with G's and that A's match with T's to form the "sister" strand. To answer the second part of the question students needed to again match letters in sequence, although the matching partners are somewhat different between DNA and RNA strands. The pairing partners between DNA and RNA strands were given in text pages and teacher presentations.

For the remaining parts of the above task, students needed to know something about the triplet coding procedure. To determine the particular amino acids produced, students needed to match three-letter codes given for each amino acid in their textbooks with each group of three bases (letters) on the messenger RNA segments determined for the first part of the question. On a second section of this task, students were required to work backwards, beginning with a given sequence of amino acids and determining corresponding base sequences on messenger RNA and then DNA strands.

Although students could have accomplished this task without demonstrating an understanding of the DNA coding concept in terms of base sequencing and protein production, they were required to replicate the somewhat complex procedural steps involved in the sequential pairing of letters on DNA, messenger RNA, and transfer RNA strands. This procedure had been presented to students in teacher lectures, textbook readings, and film loops. The teacher also had students call out answers as she worked part of the first question on this task before students began independent work. In addition, students were allowed to correct answers during the in-class checking of products with no apparent grade penalty. This checking episode therefore served as a resource for completing the work.

A second type of question covering the DNA coding concept was found on Tasks 1 (a homework assignment) and 5 (an exam). For these tasks, students were required to provide brief explanations of the DNA code. For example, Task 5 included the following question:

"The code in DNA is the triplet code. This means that·"

These questions required some description of the meaning of the coding procedure used in Task 4. Task 26 (the final semester exam) contained a similar recognition question in multiple-choice form as follows:

The specific protein produced in a cell is directly related to the:
A. order of the bases in the DNA molecule
B. order of the sugars in the DNA molecule
C. kind of ATP a person inherited
D. mitochondria in the cells

This question required some recognition of the relationship between DNA base sequencing and protein production.

Students were required to recognize appropriate sequential orderings of cell events involved in these processes for both exams (Tasks 5 and 26) as in the following example:

What is the correct summary of events in cells?
A. DNA---proteins---RNA
B. DNA---RNA---proteins
C. RNA---DNA---proteins
D. RNA---proteins---DNA

Tasks 5 and 26 also required students to demonstrate some understanding of the effects of nucleic acid mutations by providing brief explanations (or diagrammatic representations) of given mutations. For example, one question on Task 5 read as follows:

What would be the effects of having a mutation in DNA of the deletion of two pairs of nucleotides? Show or describe the results of such a mutation. Use words and/or diagrams.

To answer this question students needed to describe or represent the coding procedure used to make the required translations for Task 4. A representation of this particular type of mutation would require following the procedural steps involved in pairing letters on DNA and RNA strands, as well as representations of the procedural consequences (i.e., changes) resulting from the deletion of two of those letters. A short-answer essay description of the results of this type of mutation would not require the replication of appropriate procedural steps, but would require some demonstration of an understanding of the relationship between DNA sequencing and protein production. The teacher had not previously illustrated the effects of base deletions although she described what deletions were. Students would have needed to integrate algorithmic and conceptual knowledge to answer this question.

Task 5 also required the listing of causes of DNA mutations. This question required recall level operations as mutation causes were also listed during teacher presentations.

Task 26 also covered the mutation content in a multiple-choice question as follows:

> If a person was born with a mistake in his DNA so that a certain enzyme was missing, what result can you be <u>certain</u> would occur?
> A. He would die.
> B. One certain chemical reaction that should occur in his cell would <u>not</u> occur.
> C. There would be no effect on his cell functioning.
> D. His cells would be unable to divide.

This question does not require an understanding of the procedure or significance of base mutations, but rather the recognition of a connection between enzymes and their function.

One last requirement for Task 5 was the identification of DNA research areas of interest to students. Short descriptive essay responses were required for this question, which read as follows:

> If you had all the money and materials necessary, which area of DNA study would you choose for your own research? In other words, if you could solve some problem related to DNA and its applications, what would you want to find out?

No "areas of DNA study" had been specifically identified or discussed in teacher presentations or textbook readings. Students apparently needed to be creative here to come up with ideas related to problems associated with DNA applications.

<u>Summary</u>. Four of the five tasks (Tasks 1, 4, 5, and 26) contained comprehension level components to some degree. Two of these tasks (Tasks 1 and 4) composed only minor portions (less than 3%) of students'

terms grades. Although the final semester exam constituted 50% of students' semester grades, less than 1% of this task contained comprehension level components related to Strand 1 content.

One fourth of the other major exam grade (Task 5) was composed of comprehension level components. Although this was a relatively major task in terms of grade weight, the total contribution of comprehension level components to 6-week term grades was small, again less than 3%. In addition, only a narrow range of student answers were accepted by the teacher as correct for questions demanding recall- or procedural-level skills alone while a broad range of student answers were accepted for many questions which also required some comprehension level skills.

Student Understanding of Strand 1 Content

Most students were able to provide or recognize term definitions, list structural components of the nucleic acids, sequence cell events, and perform procedural manipulations successfully to determine replication, transcription and amino acid sequences. These manipulations required recall or procedural operations.

These portions of tasks required precise answers which were stringently graded by the teacher. Student grades, however, may have been reflective of "corrected" work only in some instances, as students were permitted to correct answers after exchanging papers with classmates during the checking and discussion of work before papers were handed in to the teacher for grading.

Although these portions of tasks required the use of a number of procedural steps for pairing base letters in the determination of replication/transcription products or amino acid sequences, they did not necessarily require an understanding of the processes themselves or the

DNA coding concept underlying the procedural manipulations. When students were actually required to utilize higher level comprehension skills for portions of later tasks, their performance was poor. For example, Task 5 included the following question:

"Show or tell, with words and/or diagrams, how DNA replicates."

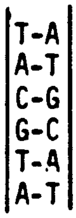
This question required more than the mere matching of letters to produce end products. It required some description or representation of events involved in the replication process, that is, the separation of double-stranded DNA segments and consequent attachment of free-floating nucleotides. It also required some description or representation of the sequence of events involved in the process.

This question could have been answered by the memorization of the following text passage:

> DNA "unzips" its two halves. Nucleotides then attach to the proper bases. In the end, two duplicated DNA molecules are formed.

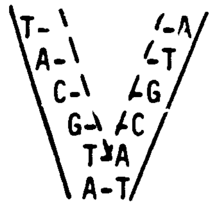
However, two thirds of the students attempted to provide illustrations of the replication process by drawing and labeling DNA (or RNA) strands in various phases. This process had been explicitly represented in prose and diagrammatic form in text pages, film loops, and teacher presentations. The specific diagrams used in these instructional sources, however, contained several components (the text diagram contained 66 separate segments) and would have required extensive memorization for duplication on exams. Although the specific base letters used in the teacher's example during a whole class presentation are not available, the teacher's diagrammatic representation of the replication process was similar to the one given below:

Figure 1



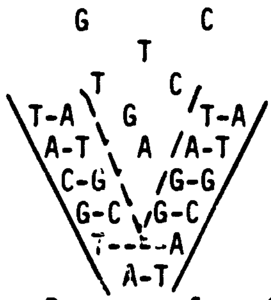
A double-stranded DNA molecule

Figure 2



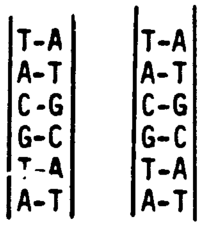
The two strands "unzip" and begin separating

Figure 3



Bases on free-floating nucleotides attach to the exposed bases on the separating DNA strands.

Figure 4



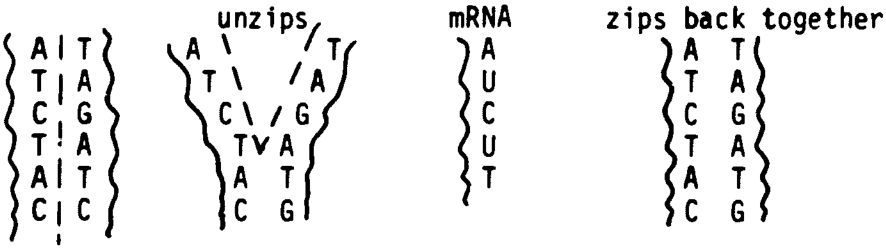
The unzipping and joining of free-floating nucleotides continues until two new double-stranded DNA molecules are formed.

The base thymine (T) pairs with the base adenine (A) and the base cytosine (C) pairs with the base guanine (G).

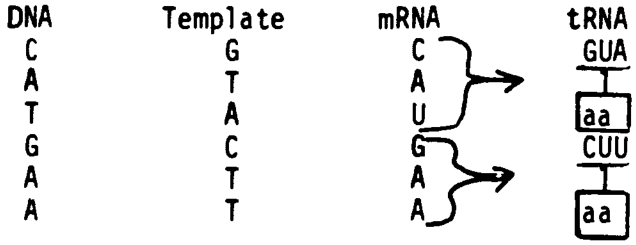
Although most students provided diagrammatic representations of this process to answer the question, many drew sketches of DNA/RNA segments in diagrams that represented various combinations of replication, transcription, and protein synthesis processes. More than 78% of the students were unable to represent the replication process accurately to receive full credit for their answers. Poor student understanding of this content was obvious as DNA and RNA strands were mislabeled, relevant events omitted, and labeled strands matched with inappropriate events as in the following examples:

Student answers not accepted by the teacher for full credit:

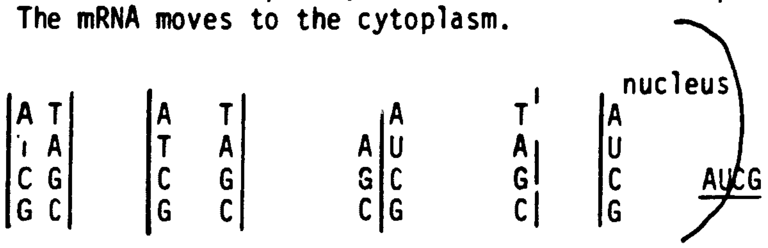
Example 1:



Example 2:



Example 3: The DNA strand splits, it takes on RNA then splits up. The mRNA moves to the cytoplasm.



Approximately 65% of the students, however, did accurately represent some component of the replication process for this question. For example, the representation given in Example 1 above illustrates the separation of DNA strands with appropriately matched nucleotide bases. The diagram is inaccurate, however, in that it appears to show some combination of DNA and RNA strands rather than the combining of free-floating nucleotides to exposed bases on the separating DNA strands to form two double-stranded DNA molecules. Students who did accurately represent some component of the replication process received partial credit for their answers (usually three of the total nine points allotted to this question).

Similar problems were apparent in relation to the protein synthesis process when students were required to describe or explain the significance of concepts underlying procedural manipulations. For example, Task 5 included the following test item:

"The code in DNA is the triplet code. This means that:

Over 47% of the students were unable to provide the required connection between DNA base sequencing and protein production to answer the question given ab`'e for Task 5. Most student answers to this question that were not accepted by the teacher for credit made reference to groupings of three (nucleotides or bases) but not to corresponding amino acid sequencing or protein production as seen in the following examples.

Student answers not accepted by the teacher for credit:
1. There are three bases.
2. DNA has a 3 base code.
3. Three bases code or match with three other bases.

It is the DNA coding concept that forms the basis (and thus gives meaning to) the procedural manipulations required to determine transcription and protein synthesis end-products. DNA strands contain various sequences of four nucleotide bases. Each sequence of three bases functions as a code word for a particular amino acid. In transcription, DNA directs the synthesis of RNA by splitting and exposing nucleotide bases which attach to bases on free-floating nucleotides such that only one particular base will pair with each base exposed on the DNA molecule. The three-letter code word is thus transposed onto RNA strands (called messenger RNA) which then move out of the nucleus and into the cytoplasm where they act as templates for amino acid assemblage.

During protein synthesis, other strands of RNA (called transfer RNA) in the cytoplasm combine with amino acids with each amino acid combining with segments of RNA containing a particular sequence of <u>three</u>

bases. Thus, each sequence of three bases codes for one amino acid. Strands of transfer RNA then move to the RNA templates where bases on each strand line up (again, with appropriate base pairing). The amino acids located at the ends of the transfer RNA strands are thus assembled in a particular sequence to form specific proteins. It is, therefore, the sequence of amino acids, determined by the sequence of bases on DNA strands, that determine which specific proteins are formed. It is in large part the particular proteins formed that determine individual make-up or phenotype.

Both the teacher and text discussed the relevance of the DNA code in this manner. The procedural manipulations for determining transcription and amino acid sequences were given in terms of the underlying triplet code during teacher presentations. Students were reminded that it was through this coding procedure that DNA determined amino acid assemblage and thus what proteins were formed and in this way controlled the physical and chemical make-up of individuals.

Despite the teacher's attempt to relate the underlying conceptual knowledge to the required procedural manipulations, students appeared to replicate procedures accurately without demonstrating an understanding of these concepts when presented in a descriptive format as given above for Task 5. However, the majority of students were able to recognize successfully the relationship between DNA base sequencing and protein production when presented in a multiple-choice format on a consequent task (Task 26--the final semester exam). This task included the following question:

> The specific protein produced in a cell is directly related to the:
> A. order of the bases in the DNA molecule
> B. order of the sugars in the DNA molecule
> C. kind of ATP a person inherited

D. mitochondria in the cells

Note that although students recognized the relationship between DNA base sequencing and protein production for this task, at least 20% of them did not appear to recognize the relationship between that information and DNA coding of amino acids as demonstrated by their performance on another question found on this task. This question read as follows:

> How many amino acids would the above strand of DNA (ATTGACATC) code for?
> A. one
> B. two
> C. three
> D. nine

Again, each group of three bases (or letters) code for only one amino acid. There are six bases represented on the DNA strand given above. The correct answer then is C, or three amino acids.

Students had not, in fact, been required to duplicate the amino acid assemblage process except on the one occasion previously discussed for Task 4. It was noted that high student grades on this task may have been reflective of corrected work only. Therefore, students may not have been as proficient in performing the procedural manipulations as student grades indicated. The use of checking episodes, which served as resources for correcting or completing work before products were handed in to the teacher for grading, may have reduced the teacher's ability to monitor student understanding or procedural proficiency.

Similar difficulties with the DNA coding concept were apparent on a task that required some description or diagrammatic representation of nucleotide mutation in terms of DNA base sequencing and protein production. For example, Task 5 included the following question:

> What would be the effects of having a mutation in DNA of the deletion of two pairs of nucleotides? Show or describe the results of such a mutation. Use words and/or diagrams.

If two pairs of nucleotides were deleted in a DNA strand, the appropriate base sequencing would be interrupted. The consequent base sequencing would be translated to RNA strands during transcription, and a different sequence of amino acids would be assembled during protein synthesis. Thus, different proteins would be formed. The transcription/protein synthesis events would need to be illustrated and then compared to those events in the case of base deletions for diagrammatic representations of mutation effects. This would require the follo g of specific procedural steps for the representation and sequencing of relevant events and products.

The mutation content was covered only briefly in teacher presentations and mainly in episodes during which the teacher listed mutation causes and commented that they resulted in the production of "incorrect pr teins." Neither text pages nor teacher presentations had exposed students to either diagrammatic representations or specific procedural manipulations in relation to nucleotide mutations. Students needed to integrate knowledge concerning what nucleotide deletions were with procedural manipulations for determining amino acid sequences from given DNA strands to answer the question in diagrammatic form.

Although students had been previously taught and had used the procedural manipulations for determining amino acid sequences, they had not been exposed to information concerning deletion mutations. Because students had not been given previous illustrations and task opportunities to practice this particular combination of content, it is not surprising that student performance was poor on this test question, with two thirds of the students unable to describe or represent these events in any manner to receive credit for their answers. The majority of students attempted to provide diagrammatic representations.

Summary. In summary, although students' grades indicated an ability to follow procedural steps in dealing with the Strand 1 content, their performance was poor on portions of tasks that required descriptions or diagrammatic representations of:
(a) replication/transcription/protein synthesis processes or
(b) concepts underlying procedural manipulations required to determine end products of these processes. Students did not consistently demonstrate an understanding of the processes and concepts which gave meaning to the procedural manipulations. The students' use of in-checking episodes as resources to correct or complete work before products were handed to the teacher for grading may have, in fact, reduced the teacher's ability to monitor individual student understanding of concepts and procedural proficiency. In addition, the lack of classroom task opportunities to practice certain procedural manipulations may have resulted in poor student performance on exam questions requiring the integration of procedural and conceptual knowledge.

Content Strand 2: Cellular Growth and Reproduction as Inheritance Mechanisms

The second group of tasks focused on cellular growth and reproduction and the application of principles involved in:
(a) gene/chromosome distribution patterns (laws of segregation and independent assortment), (b) gene expression/inhibition (dominance and

recessiveness), and (c) gene/chromosome linkage (autosomal/sex chromosome linkage). Some of these tasks also required statistical analysis in the computation and interpretation of chi square values in determining the fit of experimental with expected results of monohybrid crosses (i.e., matings).

Strand 2 content was covered in teacher presentations and work on 24 of the 30 class sessions devoted to the genetics unit. There were 22 tasks that dealt with Strand 2 content. This included seven homework assignments (Tasks 6, 8, 11, 15, 16, 19, 21, and 23), five laboratory activities (Tasks 2, 7, 9, 22, and 24), four quizzes (Tasks 10, 13, 14, 17, and 20), and four major exams (Tasks 12, 18, 25, and 26).

Task Demands for Strand 2

Cellular division. Students were required to make a variety of manipulations with Strand 2 content including the provision of term definitions, the listing and description of cellular division stages, and the determination of division end products. In number of instances, these portions of tasks could have been accomplished by recall-level operations alone (for exams) or by copying definitions, lists, or event descriptions from handouts or text pages (for homework assignments). Some tasks that appeared on the surface to require an understanding of cellular division processes, could in fact have been answered by "search and match" operations. For example, students were required to answer fill-in-the-blank questions for a homework assignment (Task 8) that appeared to require the recognition of standard chromosome numbers in body and gamete cells. Many of these questions, however, were almost exact duplicates of sentences given in dark print in the text. For example, this task included the following questions and relevant text passages:

Task Question: Each gamete contains only ____ from each ____.
Text Passage: Each gamete contains only one chromosome from each homologous pair.

Task Question: When sperms and eggs are joined in fertilization, the _____ number is restored.
Text Passage: Both sperm and egg have the haploid chromosome number. When they are joined in fertilization, the diploid number is restored.

These items therefore required the matching of dark print text passages to worksheet questions for successful completion.

Task 9, a lab activity, required the microscopic examination of prepared tissues slides from onion roots. Students were required to recognize, sketch, and label cellular components in cells found in each of the mitotic division stages. For this task, students needed to compare tissue specimens with diagrammatic representations given during teacher presentations or found on handouts and text pages. Students worked with partners on this lab and so received peer as well as teacher assistance in the identification of division stages during individual and small group interactions.

Students were also required to compute chromosome numbers in gamete or body cells for six tasks (Tasks 8 10, 11, 12, 25, and 26). For example, one homework assignment (Task 10) included the following questions:

If the diploid number of chromosomes in corn is 20, what is the haploid number?

The diploid number represents a full set of matching pairs of chromosomes. The haploid number represents a set of chromosomes containing only one member of each pair found in the original cell. The diploid number is reduced to the haploid number by the meiotic division process in the formation of egg and sperm cells. Although the teacher explained and related the meiosis process to the computations made for similar problems during whole-class presentations, students needed only to know that the haploid number is equal to half the diploid number to answer these types of questions. This required simple calculations that did not necessitate an understanding of the haploid/diploid numbers in terms of homologous sets of chromosomes.

Two of these tasks (Tasks 8 and 10), however, required an explanation of the origin of homologous chromosomes found in body cells. Although students were not required to provide answers in terms of fertilization or the rejoining of chromosome pairs, the teacher stated that students were to have indicated that one member of each homologous pair had come from each parent, an answer that could have demonstrated an understanding of the meiotic process.

Students were also required to compute total nonhomologous chromosome combinations possible in gamete cells for two tasks as required for the following question taken from a homework assignment (Task 10):

> How many different combinations of chromosomes are possible for one human male in his sperm? Give the mathematical expression or appropriate number.

Because the teacher had used this same example during a whole-class presentation, however, students could have memorized and provided answers without performing the appropriate procedural operations. However, they were required to solve similar, novel problems for a subsequent homework assignment (Task 11). For this task, students had been required to assign pairs of traits to two and three pairs of homologous chromosomes and then diagrammatically represent and label cells with these traits and meiotic end products. For example, the first part of this task read as follows:

> Assign pairs of traits to two pairs of homologous chromosomes. Show the original cell diagrammatically with these two pairs of chromosomes marked or tagged. If the cell you showed was a primary spermatocyte about to undergo meiosis, what are the possible combinations of chromosomes his sperm could end up with?

Students were required to perform s ilar operations beginning with three sets of homologous chromosomes for the second part of this task. This task required students to illustrate the meiosis process by determining all possible chromosome combinations resulting from the segregation and independent assortment of chromosomes. Each sperm had to contain one chromosome from homologous pair and each sperm represented had to contain a different combination of nonhomologous chromosomes. This required an understanding of the division process and utilization of relevant procedures.

The teacher reduced the cognitive demand of this task somewhat by providing: (a) examples of appropriate characteristics for homologous chromosomes and corresponding diagrammatic representations of original cells, and (b) one possible end product on the worksheet. Students could have merely substituted a new set of terms representing different characteristics and then copied the teacher's example for the first parts of these questions. Nonetheless, students were required to demonstrate an understanding of segregation and independent assortment principles by determining <u>all</u> possible chromosome combinations.

Task 10 and two subsequent exams (Tasks 12 and 26) required students to explain or describe the significance of meiosis as in the following examples:

> From Task 10: Give two important reasons that meiosis is necessary when living organisms mix sperm and eggs.

From Task 12 Why is the special kind of cell division called meiosis necessary?

The importance of reduction division was discussed in text pages and teacher presentations in terms of the stabilization of chromosome numbers from generation to generation.

Tasks 14, 15, 18, and 26 required students to interpret: (a) given genotypes in terms of phenotypic expression, or (b) given phenotypes in genotypic terms. For example, Task 14 included the the following question:

In Guinea pigs, short hair (S) is dominant over long hair (s). What is the phenotype of a pig who is Ss?
A) Homozygous
B) Heterozygous
C) Short hair
D) Long hair

Students needed to know that the term "phenotype" referred to physical appearance and that the characteristic associated with the capital letter would be the one expressed to answer the above question. This required some interpretation of the meaning of terms as well as application of the procedural rules for translating symbolic representations into corresponding physical attributes.

Students were required to perform the reverse process, translating given phenotypes into genotypic symbols for Task 18.

Tasks 14, 18, 25, and 26 also require the determination of genetic make-up (symbolic representation) of potential gametes resulting from meiotic division of given cell types. For example, Task 14 (a homework assignment) included the following question:

If an individual is Aa for a certain trait, what kinds of egg cells are correct for her to produce? A, Aa, AA, a, AB

The procedures involved in these types of translations are derived from the application of the law of segregation (pairs of genes are separated in forming gametes). Many of these questions could have been answered, however, simply by knowing that gametes (egg or sperm cells) contain only one letter, as all single letter choices in many of the questions were correct answers for three of the four tasks. In addition, the teacher used some of the same examples during previous whole-class presentations. Students could have therefore utilized memorization-level operations alone to produce correct answers.

<u>Monohybrid problem solving</u>. Students were required to solve monohybrid genetics problems, determining geno- and phenotypic results of various crosses (i.e., matings) for five tasks (Tasks 15, 18, 19, 21, 25, and 26). For example, Task 15 (a homework assignment) included the following question:

> Remember, capital letters are dominant and small letters are recessive: B=brown eyes, b=blue eyes
> Heterozygous brown eyed (__) x Heterozygous brown eyed (__)
> 1. Fill in the genotype of each parent.
> 2. Set up a Punnett square, with list of possible sperms and eggs.
> 3. Fill in the possible combinations of offspring.
> 4. List possible genotypes with expected ratios.
> 5. List possible phenotypes with expected ratios.

This kind of problem required a combination of comprehension and procedural operations. To begin with, students needed to know that the heterozygous condition is presented by the combination of an upper and lower case form of the same letter (e.g., Bb). These letters represent the genetic make-up (genotype) of the individual. Students were then required to determine possible sperm and egg resulting from the given cross (Bb x Bb). Each set of letters represent genes found on homologous chromosomes in one individual (parent). (The "x" is the sign used to represent the terms, "is crossed or mated with.") Gamete arising from the individuals in this particular problem could contain either the "B" or "b" form of the gene. This is an application of the law of segregation.

To determine the possible combinations of genes that could result in offspring from this mating, potential genotypes of gametes from one parent are listed separately across the top of a grid (Punnett square) while the potential genotypes of gametes from the other parent are listed similarly along the left-hand side of the grid. To determine the possible combinations of genes arising from fertilization, students then needed to combine their letters inside the grid as follows:

	B	b
B	BB	Bb
b	Bb	bb

Students were next asked to give "expected ratios." In other words, they were required to determine the probability of given genotypes (and corresponding phenotypes) resulting in offspring of the mating. Monohybrid heterozygous crosses result in given geno- and phenotypic ratios. These ratios could have been memorized or determined directly from the Punnett square results.

Tasks 15 and 18 (an exam) included one instance of a monohybrid cross involving incomplete dominance. The teacher indicated that the heterozygous condition in these problems resulted in an intermediate form rather than the typical dominant/recessive pattern.

Three of these tasks (Tasks 19, 21, and 26) required students to solve or recognize solutions to monohybrid problems involving sex-linked traits. For example, Task 19 (a homework assignment) included the following question:

> Hemophilia is a disease caused by a recessive gene carried on the X chromosome. Hemophilia=h, Normal blood clotting=H

> If a man who is normal married a woman who is normal, but who carried the recessive gene for hemophilia, what chance do their children have of getting hemophilia? List boys and girls separately.

Similar problems were found on two exams in multiple-choice form.

Recessive traits linked to the "X" chromosome in males are expressed in the individual, while females need two copies of the recessive gene to show the trait. Again, these problems required a combination of procedural and comprehension-level operations. However, students were permitted to discuss and correct their answers for two homework assignments (Tasks 15 and 29) in small peer groups before work was turned into the teacher for grading. Not all students were therefore required to perform the procedural or comprehension-level operations on their own to successfully complete the task.

The final semester exam (Task 26) also required the application of inheritance principles in determining the genetic make-up of parents from given offspring phenotypes. This question required comprehension-level operations in the application of principles derived from chromosome distribution patterns.

For Task 21, students were given the results of two monohybrid crosses and to: (a) determine probable inheritance patterns from given results, (b) determine geno- and phenotypic results of crosses assuming a particular inheritance pattern, and (c) determine the fit of expected with given results by chi square analysis. This task required complex algorithmic and comprehension-level operations in: (a) the solving of monohybrid problems (including sex-linked traits), (b) the application of inheritance principles in the determination of sex or autosomal chromosome linkage and dominant/recessive trait expression, and (c) the statistical analysis of expected and given phenotypic outcomes.

Students again discussed and modified answers for this task in small peer groups before work was turned into the teacher for grading. The cognitive demands of the task may, therefore, have been reduced for some students as the answers were copied according to others' answers.

One lab task that gave students some hands-on experience with monohybrid cross content was Task 24, which required students to determine if they had a variety of given characteristics. They were to record their results in table form and determine their possible genetic composition for each trait. For example, the lab handout included the following questions:

> In this experiment you will investigate the inheritance of some human characteristics. Both or you will be testing yourself to whether or not you inherited a particular characteristic. In your lab notebook, make a short chart like the one on the board. Record the appearance and your possible gene combination. For extra credit, select any three of the traits and do a family pedigree for each of them.
>
> 1. Some people can bend the distal or end joint of the thumb back beyond the angle of 45 degrees. This is called a "hitchhiker's thumb." A recessive (h) gene determines this ability. A dominant gene (H) in most people prevent them from bending this joint back farther than 45 degrees. Could you hitch a ride?

In the above example, a hitchhiker's thumb could only be represented by "hh." A normal thumb could be represented by "Hh" or "HH." These manipulations involved the translation of determined phenotypes into genotypic symbols. The extra credit portion of this task required somewhat more extensive manipulations. Parental and filial phenotypes needed to be obtained by testing family members and likely corresponding genotypes determined accordingly.

One other task (Task 25) also required students to determine the potential genetic make-up of individuals with given phenotypes. This task included the following set of questions:

For the next items assume that the ability to roll the tongue is dominant to the lack of this ability. Mr. and Mrs. Jones could roll their tongues. They had a daughter, Sally, who was unable to roll her tongue. Mr. Smith could roll his tongue, but Mrs. Smith could not. They had a son, John, who could roll his tongue. Mrs. Smith and Mr. Jones died. Mr. Smith married Mrs. Jones. They had a daughter, Mary, who could roll her tongue. What were the genotypes of all of the individuals involved? Key: A) RR, B) RR, C) rr, D) cannot be determined. Determine the genotypes for Mr. Jones, Mrs. Jones, John Smith, Mr. Smith, Mrs. Smith, Mary Smith, and and Sally Jones.

These questions required algorithmic and comprehension level operations in the application of inheritance principles.

Although students were required to solve monohybrid problems for five tasks, they were required to recognize given solutions in multiple-choice test items for Tasks 25 and 26.

The fruit fly cross. One of the most complex tasks related to monohybrid problem solving accomplished in this class was the fruit fly cross. Students were required to set up and carry out monohybrid crosses with fruit flies with normal/mutant trait variations for Task 22. Students began work on the fruit fly cross early in the unit with Task 2 when they made and recorded microscopic observations of characteristic distinctions between male and female flies. The final product for this task was a written report that included a title, statement of purpose, and summary of sex distinctions given in chart or paragraph form. Students worked with partners on this task, although each student turned in a separate report. Both the title and statement of purpose for the written report were provided orally by the teacher.

During work sessions for this task, both the teacher and an experienced lab assistant helped students to identify distinguishing characteristics. The teacher also called on students to provide examples of distinguishing characteristics orally during a whole-class discussion of the lab before reports were turned in for grading. These resources may have modified the task demands for some students from the recording of observations to the recording of other student or teacher statements concerning sex distinctions. For a subsequent practical lab exam (Task 8), students were required to utilize observational skills to identify the sex of three fruit flies.

Task 22 involved the mating of two generations of fruit flies with a particular normal/mutant trait variation (i.e., body structure or eye/body color variations). Students worked with partners to set up crosses although written lab reports were handed in by each student. Reports were to have contained a record of dates and procedures followed and observations regarding the numbers and appearance of adult and larval flies. Students were to determine and record probable inheritance patterns (i.e., autosomal/sex-linked, dominant/recessive) for the trait under consideration according to observed results. Next, assuming a particular inheritance pattern, they were to determine and record expected geno- and phenotypic results of such a cross using the Punnett square. The final requirement for the written report was the chi square analysis of results. Students were to compute and then give sentence explanations of the significance of the probability values obtained.

This was a long-term task with 17 of the 30 class sessions devoted to instruction or work. The task required observation and recordkeeping skills as well as procedural (algorithmic) operations. This task required comprehension level operations in: (a) the application of general principles in the determination of probable trait inheritance patterns, and (b) the explanation of the meaning of probability values obtained. However, most students received extensive teacher assistance with the work as the teacher identified sex, traits, and stages of development for given flies, and provided expected results and explanations of the significance of probability values obtained for individuals in response to disruptions in student engagement. For example. the teacher's assistance is recorded in narrative data on 1/4:

> Now Maria, Helen, Misty, Elaine, and Edwin all stand around the teacher in a circle. The teacher says something like, "So this is what you should expect for the F_1 (first filial generation), okay?" Pat shakes her head yes and walks away. The teacher talks with Helen now saying, "Okay, bring me your records and I'll tell you what you should have gotten . . . (p. 10)

In addition, the teacher provided written corrective feedback on student products that were collected twice before they were turned in for final grading. In response to student errors, the teacher had some students begin the cross again, and others share results as time ran out toward the end of the unit. The teacher asked students to offer written explanations of possible sources of error in experimental results and, in one instance, helped a group set up another cross for comparative purposes. However, continued student errors and requests for assistance led the teacher eventually to provide the requested explanations for some students. For example, one student described the teacher's assistance as follows during an interview session:

> Interviewer: Oh, okay you said that you wanted to cross black-bodies males with wild (brown-bodies) females but that something happened, you "messed up". . . How did you know your results were messed up?
> Student: Because we had . . . we had wild, but we weren't supposed to get any wild in our results.
> Interviewer: Okay, how did you know you weren't supposed to get any wild in your results?
> Student: Ms. _____ told us.
> Interviewer: . . . I see. So she told you you didn't get the results were supposed to have gotten.
> Student: . . . Well, first she told us that we might have messed up on our first cross, and we figured out that

maybe it was a black female that we messed up, or we had an extra or something . . . and then she (teacher) asked us to figure out what would change the outcome, and we couldn't do it, so she told us.

Interviewer: Okay. She wanted you to try to figure out how the outcome would have changed if you had gotten a black female mixed in. Okay. So you weren't able to figure that out so she gave you that information.

Student: Yes.

Interviewer: Did you then record that information in your lab book?

Student: Yeah.

Additional evidence of teacher assistance is provided here from narrative data taken on 1/8.

> The teacher talks with Daniel now and Edwin listens in. The teacher tells Daniel that at least one of the fruit flies that they identified as a male was really a female and this is why he got the results that he did for one group. Daniel says okay and goes back to his seat and tells Janis this. (p. 11)

Extensive teacher prompting in response to student errors and requests for assistance appears to have modified the task demands so that all students were not required to: (a) manipulate actual observational results, (b) determine probable inheritance patterns on their own, (c) determine expected results assuming probable inheritance patterns, or (d) explain the meaning of probability values obtained. The task did, however, require the manipulation of complex algorithms in the computation of chi square values.

Dihybrid problem solving. For Tasks 16, 17, 18, 25, and 26, students were required to solve dihybrid problems. For example, Task 16 (a homework assignment) included the following set of questions:

In armadillos, normal eyes (A) are dominant over crossed eyes (a); hard shells (B) are dominant to paper shells (b); and normal tails (D) are dominant to spiked tails (d).
1. State genotypes of parents.
2. Work by the Punnett square method to obtain expected phenotypes and ratios.
3. Work by the probability method to obtain expected phenotypes and ratios.
Problem: Homozygous normal eyed, homozygous hard-shelled armadillo male x cross-eyed, paper-shelled armadillo female.

The solutions to dihybrid problems involve somewhat more complex procedural manipulations than monohybrid problems.

The procedural manipulations required for solving these problems require the application of the law of segregation (as in the monohybrid problems) as well as the application of the law of independent assortment.

During meiosis, homologous pairs of chromosomes (and, therefore, gene pairs) separate. Each member of a homologous pair is distributed to gametes completely independently of the way other gene pairs on other chromosomes are distributed. This distribution pattern refers only to genes on nonhomologous chromosomes and is the basis for the law of independent assortment.

These problems require the application of complex procedural manipulations and the recognition and provision of symbolic representations of genetic terms, as well as an understanding of the meaning of those terms. For Task 16, however, students were again permitted to discuss and correct the answers in small peer groups before papers were handed in to the teacher for grading. Therefore, all students were not necessarily required to have performed the manipulations on their own to produce correct answers.

Students were also required to solve a dihybrid problem for Task 17 (a quiz). Because this problem was identical to one found on the previous homework assignment, students could have answered the question at a memorization level alone. Problems given on the final exams (Tasks 25 and 26), however, were not identical to the ones worked in class or for previous assignments. Students were required to recognize problem solutions in multiple-choice test items for these tasks.

Students were also required to recognize the mode of inheritance for one dihybrid cross for Task 26. This task included the following multiple-choice questions:

> Tallness (T) is dominant to dwarfness (t), while red flower color is due to the gene (R) and white to its allele (r). The heterozygous condition results in pink (Rr) flower color. A dwarf red snapdragon is crossed with a plant homozygous for tallness and white flowers.
>
> 1. What are the genotype and phenotype of the F_1 generation?
> A) ttRr---dwarf and pink
> B) ttrr---dwarf and white
> C) TtRR---tall and red
> D) TtRr---tall and pink
>
> 2. The mode of inheritance is:
> A) dominance in both pairs of genes
> B) lack of dominance in both pairs of genes
> C) lack of dominance in one pair of genes
> D) multiple alleles

This particular problem involves incomplete dominance in a dihybrid problem, a combination not previously worked during teacher presentations or tasks. Students had, in fact, worked monohybrid problems involving incomplete dominance and could have utilized comprehension level operations to integrate manipulations involving incomplete dominance and dihybrid problems to generate answers to this question. This content integration would have required comprehension-level operations.

Student Understanding of Strand 2 Content

Monohybrid problem solving. Student difficulties were apparent on tasks that required solutions to monohybrid crosses involving sex-linked traits. For example, 50% of the students were unable to correctly answer the following question taken from Task 26 (the semester exam):

> Color blindness is caused by a recessive gene on the x chromosome. If a color blind man marries a normal woman who is carrying a gene for color blindness, what would you expect in their children?
> A) One half of the sons would have normal vision
> B) All of the children would be color blind
> C) All of the daughters would be color blind
> D) None of the daughters would be carriers

Characteristics linked to the sex chromosomes show a different pattern of expression than those linked to autosomal (nonsex) chromosomes. This is because males have a set of nonhomologous sex chromosomes in their body cells (represented by an "X" and a "Y"). Nonsex determining characteristics linked to either member of the set are expressed in males. Females, on the other hand, have a double set of X chromosomes in their body cells. The interaction of genes on this homologous set follows the dominant/recessive patterns typical of those linked to autosomal sets. In the above example, females would require two copies of the color blindness gene for physical expression, whereas males would be color blind with only one copy of the gene present.

Students were required to solve crosses involving sex-linked genes for two previous homework assignments (Tasks 19 and 21) following a whole-class teacher presentation of the content. Student grades for Task 19 were high, with all students receiving 80% or more of the total possible points. Students were asked to discuss answers in small peer group settings on the day after the work was assigned, before products were collected by the teacher for grading.

Student interactions during group work ranged from explanatory interchanges to the mere copying of answers. Lower-ability students tended to merely request and receive answers from peers while only higher-ability students were ever observed requesting or providing explanatory feedback. A number of students in this class consistently copied answers from peers. High grades for this task may have therefore been reflective of procedural proficiency for only a small number of students. This grading procedure reduced the teacher's ability to monitor individual student understanding or procedural proficiency.

For the subsequent fruit fly lab (Task 22), students were required to set up and carry out a two-generation, monohybrid cross. They worked with partners to determine dominant/recessive and chromosome linkage patterns for the traits under consideration from observational results. However, several students received extensive peer and teacher assistance with this task. The teacher expended a significant amount of time and energy in assisting individual students in the analysis of results in response to student errors and requests for assistance (see Task Demands for Strand 2). Nonetheless, student difficulties persisted and in many cases, the cognitive demands of the task were reduced as the teacher provided much of the requested information for individuals.

Student difficulties were apparent as over one fourth of the students were unable to determine appropriate inheritance patterns from observational results. In addition, all students who accurately provided algorithmic manipulations and interpretations for written reports were not able to duplicate or explain those manipulations during interviews. More importantly, many of the students interviewed did not have a clear idea of what a monohybrid cross was outside of a paper and pencil computation.

For example, when asked to describe what kind of a cross they did, several students used the term "wild" although they did not understand t ʟ the wild flies were the ones with the normal, opposed to the mutant, trait variation. For example, one student demonstrated very confused notions of fly characteristics and inheritance:

I: Can you tell me what kind of a cross you did?
S1: We started out with a wild female and the spineless, wait a minute, I believe it was spineless, I forgot the scientific name that she had for it. It has a floating head. But umm, that cross died and then we (mated) a black and a wild female.
I: . . . and what is "wild?"
S1: . . . it's a . . . I'm kinda confused. 'Cause we did t·· or three crosses because the flies kept dying . . . We went to black and virgin females.
I: O.K., and what did they look like?
S1: . . . the virgins, you can't really see that they're virgins, they're just (pause)
I: How did you tell them apart from the black?
S1: The black were males, the virgins were females.
I: . . . do you remember anything about patterns of inheritance that you went over in class and how that related to what you did with your flies?
S1: . . . black was dominant and virgins were recessive.

"Wild" flies in these crosses were flies showing the normal, opposed to the mutant, variation of the trait under consideration. The wild flies used in the crosses were usually females. It is important to control experimental results by preventing matings other than those desired. This student appeared to confuse inheritance patterns for given characteristic variations with the sex or virginity status of the flies. Other students appeared to have similar misconceptions but produced accurate algorithmic solutions for their products. These students tended not to make connections between the algorithms used and the conceptual genetic principles. For example, another student discusses her cross in the following interview excerpt:

I: Can you tell me what cross you had in the fruit fly lab?
S2: I had wild flies and black ones . . . we had to mate them and then see which, like how many were black and how many were wild.
I: O.K., and by wild, you mean what?
S2: They were just wild, that's what they're called.
I: What does wild look like, how could you tell if they were wild?
S2: I couldn't tell if they were wild, I could tell if they were black, so I'd just look for the black ones . . . We took out the parents of the first ones and put the babies in another bottle. But ours didn't work, so nothing happened . . . she gave us somebody else's results so we could work out the rest of the work, you know?
I: And what was the rest of the work like?
S2: We had to do these problems to figure out how close our results were to what was expected to happen.
I: Can you tell me anything more about that?
S2: No. It's just this kind of problem and you figure it out.
I: What do you think was the purpose of that lab on fruit flies?
S2: I don't even know.

Although the teacher worked sample problems during in-class instructional episodes using different trait variations, she did not explicitly connect the term "wild" to characteristic variations but noted that the wild flies were virgin females. Lack of explicit instruction in this case did not appear to facilitate student understanding or connection of monohybrid crosses with algorithmic computations.

This was a procedurally complex laboratory activity. Many flies died due to inappropriate handling techniques (e.g., ether overdose) and food supply contamination. Experimental results, in some instances, were consequently insufficient to determine appropriate inheritance patterns. These difficulties may have contributed to students' comprehension problems.

Monohybrid crosses involving sex-linked traits was one area of content that appeared to be poorly understood by many students. Nearly half of the students were unable to solve novel, sex-linked problems on an exam, Task 25, that included the following question:

> Hemophilia is caused by a gene on the X chromosome. If a woman is normal, and does not carry the gene for hemophilia, and her husband has hemophilia, what are the chances that her sons will be born with hemophilia?
> A) Zero
> B) One half
> C) All of them will have it
> D) Impossible to predict

Because all males receive their X chromosomes from their mother, none of the males resulting from the above cross would carry the recessive hemophilia gene. Even though students had worked problems with the same characteristics for a previous task accomplished in group setting, nearly half of the students were unable to correctly answer this question for the exam.

Student difficulties with the gene/chromosome, sex-linkage concept was also apparent on another question on this task (Task 25) which read as follows:

> If a gene is carried on the X chromosome:
> A) The trait is more likely to show up in women
> B) The trait is more likely to show up in men
> C) The trait will show up equally in men and women
> D) Impossible to predict

Over 63% of the students were unable to correctly answer this question. Few students appeared to understand that characteristics associated with genes linked to the X chromosome were more likely to appear in males where only one copy of a recessive gene is needed for physical expression.

Examination of tasks and instruction in this area indicated that students received limited novel problem-solving opportunities with the sex-linked content. Only four tasks required the working of sex-linked problems. Students were permitted to share answers for the first two

(Tasks 19 and 21), thus reducing the teacher's ability to monitor individual student understanding and procedural proficiency. The teacher's provision of interpretive explanations of experimental results for some students but lack of explicit instruction concerning experimental procedures and genetic concepts for others for the following lab (Task 22) did not appear to facilitate student understanding of the content. Both algorithmic and interpretive deficiencies were obvious for novel problems on final exams that required unassisted individual student performance.

Dihybrid problem solving. Student difficulties were also apparent on tasks that required dihybrid problem solutions. For example, Task 18 (an exam) included the following problem:

> In Drosophila, let N = normal body, let n = fat body, let L = normal legs, let l = thick legs. What proportion of offspring (phenotypes) would you expect in a cross between a male which is heterozygous for normal legs, and a fat bodied female with thick legs?
> Genotype of parents:
> Punnett Square:
> Expected phenotypes of offspring:

Nearly one fourth of the students were unable to give accurate symbolic representations of the given parental genotypes to begin the cross. These students were unable to depict gene combinations for multiple sets of traits.

Dihybrid problems require somewhat more complex procedural manipulations than monohybrid problems. Students must determine potential gene combinations for two sets of traits in parental gametes. The procedures for making these manipulations are derived from segregation and independent assortment principles that specify gene/chromosome distribution patterns.

Students were previously required to illustrate a combination of segregation and independent assortment principles for Task 11 (a homework assignment). This task required the diagrammatic representation of gene pairs on two and three sets of homologous chromosomes. Students were then instructed to represent genetic combinations and gametes resulting from meiotic division as follows:

> Assign pairs of traits to two pairs of homologous chromosomes. Show the original cell diagrammatically with these two pairs of chromosomes marked or tagged. If the cell you showed was a primary spermatocyte about to undergo meiosis, what are the possible combinations of chromosomes his sperm could end up with? Now add a third pair of homologous chromosomes with another pair of traits to follow through. Show the cell diagrammatically with these three pairs of chromosomes marked or tagged. If this cell were a primary oocyte about to undergo meiosis and become egg cells, what are the possible combinations you could end up with?

Over 50% of the students either didn't make the required manipulations or inappropriately represented meiotic products, demonstrating an inability to accurately illustrate the segregation and independent assortment of genes on nonhomologous chromosomes. Students were not given further practice in tasks representing the content in this matter.

The teacher had specifically stated and repeated the idea that only one member of each homologous pair of chromosomes and genes is contributed to gametes and that homologous pairs are rejoined during fertilization to restore the full haploid number.

The teacher also made reference to the idea that genes on nonhomologous chromosomes are distributed to gametes in a manner completely independent of one another. Students had little independent practice with this concept, however.

Students were subsequently required to solve mono- and dihybrid problems. The first task containing dihybrid problems was completed in small group settings and only one paper was selected for grading from each group. Again, many students copied answers from peers. This procedure reduced the teacher's ability to monitor individual student understanding on algorithmic proficiency.

Students were required to solve a dihybrid problem independently on a subsequent quiz (Task 17). This problem, however, was identical to one from the previous task and could, therefore, have been answered at a memorization level alone. Independent problem solving was required for novel dihybrid problems on final exams and unassisted student performance was poor.

Summary. In summary, limited classroom instructional opportunities for individuals to manipulate novel problem situations, accountability aspects of nontest tasks (i.e., peer group assistance), and lack of explicit instruction concerning relationships between algorithmic and conceptual knowledge appear to have resulted in poor student performance on tasks requiring individual student solutions to genetic crosses. In addition, the teacher's grading system for some tasks may have reduced her ability to monitor individual student understanding of relevant concepts and procedural proficiency.

DISCUSSION

This study focused on classwork accomplished in an introductory high school biology class during the teaching of a 6-weeks genetics unit. The class was observed every day to obtain narratives focusing on aspects of the class that related to students' assignments. Narratives included the content of teacher presentations, teacher/student and peer interactions. All text materials, handouts, and graded student products were collected. The teacher and selected students were interviewed at the end of the unit to obtain information concerning their perceptions and understanding of the work and genetics content. In analyzing the data, three questions were considered:

1. How was the genetics content translated into student assignments in this class?

2. How were assignments organized into a classroom work system, and how was this system managed by the teacher?

3. What were the apparent consequences in terms of learning opportunities for students and their understanding of the genetics content?

Students in this class were engaged in a variety of tasks ranging from short-term seatwork assignments accomplished in one session to a written report on a genetics experiment with fruit flies accomplished throughout the entire 6-weeks observation period. They accomplished work individually, in pairs, and small peer group settings. The cognitive demands of the work ranged from the mere copying of terms from text pages onto blanks on a worksheet, to complex operations requiring integration of algorithmic and conceptual knowledge.

The teacher in this class attempted to relate genetics content to students' real life knowledge about their own characteristics, and she included many questions on tasks that required students to demonstrate an understanding of basic genetic principles. In addition, she carefully sequenced tasks so that several of the assignments required students to integrate content presented in previous whole-class presentations and work. In most instances, the teacher provided explicit instruction of genetics concepts and students solved many problems for assignments. Nonetheless, students had many difficulties accomplishing work that required: a) demonstration of an understanding of the DNA base coding concept, b) the solving of dihybrid problems where students had to determine inheritance outcomes for two traits simultaneously, and c) the solving of monohybrid problems involving characteristics linked to the sex chromosomes. In addition, many showed poor understanding of their work in a major laboratory task, the fruit fly experiment.

Stuart and Dale (1971) have noted that in secondary classrooms poor student understanding of genetics problems and concepts often are a result of inadequacies in direct instruction and in student practice with the content. A close examination of the tasks and instruction containing content students had difficulties with in this case showed some inadequacies in both areas, instruction and practice. First, in some cases student difficulties appeared to be related to lack of explicit instruction. For example, a number of students did not appear to understand the distinction between alternate forms of traits linked to sex chromosomes and the sex of an organism. This confusion appeared to be due, in part, to the teacher's lack of clear instruction during work on the genetics experiment with fruit flies. During instruction, the teacher tended to refer to male but not female flies in terms of the characteristics expressed, and some students' responses to final interview questions indicated a confusion between the sex of the organism and the traits under consideration.

Thus, despite this teacher's generally careful attention to providing clear instruction, some student problems in understanding can be traced to unclear explanations. A more significant factor in this class, however, appears to be limitations in practice with the problems. A close look at the tasks containing content students had difficulties with showed students' problem solving experiences were limited in three critical ways. First, they were seldom required to solve novel problems on their own until final exams. For example, mono- and dihybrid problems were frequently accomplished in peer group settings, and products turned into the teacher tended to mask individual student's misconceptions and algorithmic deficiencies. Some studies of classroom learning (e.g., Peterson, Wilkinson, Swing, & Spinelli, 1984) suggest that lower ability students tend to do more poorly on work accomplished in group settings, and our observations lend some support to this finding. In group checking activities lower achieving students were often observed copying or accepting correct answers without discussion. Only higher ability students were observed providing or requesting explanatory feedback in their small groups.

A second limitation in students' problem-solving experiences was that during work on some assignments, extensive teacher prompting in response to student errors or disruptions in student engagement eliminated the necessity for student to make connections between the algorithms used to solve problems and genetic concepts or real life phenomena. For example, many students had difficulties with a fruit fly experiment. This task required the mating of flies with particular normal/mutant trait variations and subsequent determination from observational results of inheritance patterns in effect for these characteristics. The teacher responded to constant student requests for assistance by eventually providing much of the requested information for individuals, without uncovering and correcting students' misconceptions or sources of confusion. Because answers were provided in this manner, some students circumvented the task. That is, they were able to turn in the assignment without actually doing critical aspects of the work or understanding it. Many students who turned in written reports that were algorithmically accurate were unable to duplicate or explain those manipulations during final interview situations. Misconceptions were obvious as students described the matings and inheritance patterns proposed in terms contradictory to the algorithms given in their work. In fact, many students interviewed did not have a clear idea about what monohybrid problems represented other than paper and pencil computations.

A third limitation in students' practice opportunities with the content was that in some cases questions that appeared on the surface to require algorithmic application or student understanding of some concept could have been answered by memorization or search and match operations alone. For example, one task included a question that specified the relationship between genes in gametes and body cells. This relationship is fundamental to basic genetic principles required to solve dihybrid problems. However, the question was identical to one given in dark print in text pages and students needed only to search through the text, find the sentence in dark print, and copy terms into the appropriate blanks on the worksheet. The task could have been successfully accomplished, therefore, without an understanding of the relationship depicted in the question. In addition, problems on subsequent quizes requiring unassisted student work were at times identical to those accomplished in previous group settings and could, therefore, have been answered at a memorization level alone.

In conclusion, explicit, clear instruction along with sufficient novel problem-solving opportunities, appear to be essential for nurturing an accurate understanding of genetics. We cannot expect students to acquire algorithmic proficiency or content understanding unless they have opportunities to practice solving novel problems _on their own_. When students receive extensive peer or teacher assistance with their work, the cognitive demands of tasks are reduced for some students. Furthermore, teachers cannot diagnose individual student's misconceptions or sources of confusion if students are never required to attempt work on their own and show or discuss their work with their teacher. It would appear that although there are positive elements (i.e., peer interaction and discussion of content) to group work, it would be wise to follow or supplement these kinds of tasks with work requiring individual student performance. This allows the teacher to monitor individual student understanding and algorithmic proficiency.

In addition, teachers should respond to poor student performance on novel problems by providing further instruction and practice. In many classrooms students' poor performance on major exams or parts of exams is not often followed by reteaching and further practice. The pressures to move on to new topics in the curriculum prevail.

This study illustrates the consequences of one teacher's decisions about how students accomplished work in the classroom. What resources were made available for doing work and how students were held accountable for that work influenced the degree of information processing required for successful task completion and it had impact on students' understanding of the work. This case suggests that specific attention should be given to management issues related to classwork if science educators hope to foster higher levels of cognitive functioning.

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Table 1

Task Descriptions

Task #	Class time allocated to task	% of term grade	Description/Content Covered
1	15 min.	1	12 short answer and fill-in-the-blank questions on a worksheet concerning the structure and replication of DNA.
2	45 min.	—	Observation and summary in chart form of five differences between the male and female fruit fly.
3	1 hr., 20 min.*	less than 1	A one-question quiz over a textbook reading assignment on transcription/protein synthesis, "What is the role of ribosomes in protein synthesis?"
4	28 min.	1	7 fill-in-the-blank and matching-type questions on a worksheet over the structure/replication of DNA, and transcription/protein synthesis.
5	2 hr., 29 min.	11	29 multiple-choice, fill-in-the-blank, and short answer exam questions on the structure/replication of DNA, and transcription/protein synthesis.
6	44 min.	1	16 short answer and fill-in-the-blank questions on a worksheet concerning chromosome structure and cell division (mitosis).
7	3-7 min.	1	A practical lab exam requiring students to identify the sex of three fruit flies from microscopic observation.
8	18 min.*	—	16 short answer and fill-in-the-blank questions on a worksheet concerning gamete formation (meiosis) and fertilization.

Table 1, continued

Task #	Class time allocated to task	% of term grade	Description/Content Covered
9	1 hr., 32 min.	2	Observation/identification/diagrammatic representation of mitotic stages in onion root tip slides. (Slides observed, stages drawn, and cell parts labeled.) Also included three related short-answer questions over the content.
10	13 min.	3	15 multiple-choice, fill-in-the-blank, and short answer questions concerning cell division (mitosis), and gamete formation (meiosis)/fertiliztion.
11	21 min.	1	8 short answer questions over gamete formation (meiosis, and fertilization; laws of segregation and independent assortment.
12	46 min.	11	37 multiple-choice, matching, fill-in-the-blank, and short answer exam questions concerning cell division (mitosis), and gamete formation (meiosis); laws of segregation and independent assortment.
13	11 min.	less than 1	5 short answer questions on genetics terminology and Mendel's contribution to the field of biology.
14	18 min.	1	8 multiple-choice questions concerning genetics terms and concepts including gamete formation (meiosis)/fertilization, laws of segregation and independent assortment, and principles of gene dominance/recessiveness, .
15	1 hr., 21 min.	2	13 monohybrid genetics problems. Expected genotypic and phenotypic ratios for each of the crosses.

Table 1, continued

Task #	Class time allocated to task	% of term grade	Description/Content Covered
16	35 min.	1	5 dihybrid genetics problems. Determination of expected genotypic and phenotypic ratios of each cross.
17	—	**	Quiz involving the solving of one dihybrid genetics problem. Determination of expected phenotypes.
18	37 min.	11	14 multiple-choice and short answer questions including the solving of mono- and dihybrid genetics problems. Determination of genotypic and phenotypic outcomes.
19	47 min.	2	6 monohybrid genetics problems involving sex-linked traits. Determination of expected genotypic and phenotypic ratios and corresponding sex distinctions for each cross.
20	8 min.	**	A one question quiz over a textbook reading assignment on human genetics, "How is eye color inherited?"
21	2 hr., 13 min.*	2	2 problems involving the analysis of given results of monohybrid crosses in terms of Chi square and probability values. Involved the understanding of a number of inheritance concepts.

Table 1, continued

Task #	Class time allocated to task	% of term grade	Description/Content Covered
22	6 hr., 55 min.*	11	Long term (7 weeks) task: A laboratory activity involving the mating of wild type and mutant fruit flies. Mutation to have been one of the following: black (body color), sepia (eye color), white (eye color), or vestigial (wing variation). Students were to keep records of various characteristics as found in the F_1 and F_2 generations and determine probable inheritance patterns for the traits used in their crosses according to experimental results obtained. Students determined the fit of experimental with expected results by use of Chi square analysis. All data and analysis were to have been written up in a lab report.
23	1 hr., [illegible]1 min.	—	6 short answer discussion questions over a magazine article on environmental vs. genetic influences on physiological/psychological characteristics in humans.
24	1 hr., 19 min.*	2	Determination of students' genotypes for a variety of traits. Students were to test themselves for the traits, record results in chart form, and determine possible gene combinations for each of the traits. Family pedigrees for any three of the traits could be done for extra credit.

Table 1, continued

Task #	Class time allocated to task	% of term grade	Description/Content Covered
25	1 hr., 43 min.	11	44 multiple-choice, matching, and short answer questions concerning most of the genetics content from the unit: gamete formation/fertilization, principles of gene dominance/recessiveness, sex chromosome linkage, laws of segregation and independent assortment, Punnett square methods for determining genotypic and phenotypic results of mono- and dihybrid crosses, inheritance patterns, statistical analysis of experimental results, and environmental vs. genetic influences.
26	Unknown	__	113 multiple choice questions on the final semester exam concerning content covered in previous 6-week terms, and all of the genetics content from the unit.

* Times shared with, but not distinguishable from, other task times.

__ Task did not contribute to the term grade.

** Uncertain if these tasks contributed to term grade (could not have constituted more than 1% of the grade).

Appendix A

Topic List for Teacher 10, School 7, Period 1, Honors Biology

Topic List for Teacher 10, School 7, Period 1, Honors Biology

*Tasks Related to the Genetics Unit Handed in on These Dates.

Genetics Unit:

11/12/84

1. The teacher returned graded unit tests from the previous 6-weeks' grading term (test on Photosynthesis and Respiration) to students and read off the correct answers.
2. The teacher gave students a worksheet on DNA as a homework assignment (Task 1).
3. The teacher gave a content presentation and procedural instructions for Lab 14 (Task 2) concerning the sex differences found in Drosophila (the fruit fly).
4. Students worked on Lab 14 (Task 2) concerning sex differences in Drosophila (the fruit fly).

11/13/84

1. The teacher called on students to orally provide answers to content questions concerning Lab 14 (Task 2-Sex Differences in Drosophila) and then gave procedural instructions for the lab.
2. The teacher gave a content presentation and procedural instructions for Lab 15 (Task 22) concerning the genetics of the fruit fly (Drosophila Cross).
3. Students worked on Lab 15 (Task 22) concerning the genetics of the fruit fly (Drosophila Cross).

11/14/84

1. The teacher checked students' work for completion on the DNA worksheet (Task 1).

2. The teacher provided content presentation and procedural instructions for Task 22 (Lab 15--Drosophia Cross).
3. The teacher gave procedural instructions for the Independent Research Project.
4. The teacher showed a film loop on the importance of the nuclei in the Amoeba, and then discussed the topic by orally questioning students and using their responses for further content development.
5. The teacher gave a content presentation on DNA.

11/15/84

1. The teacher checked students' work for completion for the worksheet on DNA (Task 1).
2. The teacher gave a content presentation on DNA structure and function, utilizing student responses to oral questioning for further content development.
3. Students did an activity on the structure of DNA (put plastic colored strips representing various parts of a DNA molecule together; students needed to match appropriately colored strips--representing the four bases.) The teacher discussed appropriate matching after students completed the activity (students worked with partners).

11/16/84

1. The teacher gave procedural instructions for Lab 15 (Task 22) on the Genetics of the Fruit Fly (Drosophila Cross).
2. The teacher gave procedural instructions for the Independent Research Project.

3. The teacher gave content presentation on DNA Structure Protein and Synthesis, utilizing student responses to oral questioning for further content development.

4. The teacher showed a film loop on Protein Synthesis.

(1) *5. The teacher had students correct their own papers as she read the answers to their DNA worksheet (Task 1).

(2) *6. Students worked on Lab 15 (Task 22) concerning the Genetics of the Fruit Fly, and then handed in their work for this task and for their Independent Research Projects.

11/19/84

1. The teacher gave procedural instructions for Lab 15 (Task 22 --Drosophila Cross) and discussed answers for Lab 14 (Task 2 --concerning Sex Differences in the Fruit Fly) after both products were returned to students.

2. The teacher returned Independent Research Projects and gave accountability information regarding this task.

3. Teacher continued content presentation and film loop on Protein Synthesis (the students took notes as the teacher put information on the blackboard).

11/20/84

(3) *1. Students took a quiz over the textbook reading assignment concerning Protein Synthesis.

2. The teacher had the students do a sample exercise together in class as she wrote the work on the board for the Protein Synthesis worksheet (Task 4). The teacher then gave further content presentation and procedural instructions for the task.

3. The teacher went over the answers to the quiz question on Protein Synthesis after students' papers had been handed in (Task 3).
4. The teacher reviewed for a test by asking questions and calling on students to orally provide the answers. Questions were frequently given in the exact format as they were given on the test.
5. The teacher gave a content presentation on Mutation (students took notes).
6. The teacher gave a content presentation and procedural instructions for Task 4 (a worksheet on Protein Synthesis) and then students began work on the task.

11/21/84

1. The teacher gave procedural instructions for Lab 15 (Task 22--Drosophila Cross).

(4) *2. Grading of Task 4 (worksheet on Protein Synthesis)--students checked their own papers.

(5) *3. The teacher reviewed for Task 5, the Test on DNA/RNA Structure and Replication. Students then took the test.

4. Worksheet on Cell Reproduction (Task 6) was handed out to students.
5. Students worked on Lab 15 (Task 22--Drosophila Cross).

1/26/84

1. The teacher gave procedural instructions for a practical lab exam (Task 7--Distinguishing Male from Female Fruit Flies). Students then took the test one-by-one with a lab assistant in a back storeroom while the teacher gave a content presentation with the remainder of the class.
2. Teacher returned graded papers (specific work returned to students unknown).

3. The teacher gave a c..tent presentation on DNA and Cell Division.

4. The teacher showed a film loop on Cell Division.

5. Students worked on Lab 15 (Task 22--Drosophila Cross).

11/27/84

(5) *1. The teacher handed back gr d tests (Task 5--Structure and Replication of DNA/RNA) and read off the answers to the questions.

2. Students corrected their homework worksheet (Task 6--on Cell Reproduction).

3. The te cher showed a film loop on Mitosis and discussed this with the students.

4. The teacher gave procedural instructions for Task 9 (Mitosis Lab) and then students worked on the task.

(7) *5. A number of students retook the Fruit Fly Quiz (Task 7--Distinguishing Male from Female Fruit Flies).

11/28/84

1. The teacher gave a content presentation on the v ous stages of Mitosis.

(9) *2. Students worked on Lab 16 (Task 9--Mitosis Lab using onion root tip slides).

11/29/84

1. The teacher returned and discussed the grading of the Mitosis Lab (Task 9).

2. Students graded homework assignments as the teacher called on them to provide the answers (Task 8--Worksheet on Meiosis).

3 The teacher gave a content presentation on Meiosis and Genetic Disorders.

11/30/84

1. The students took a quiz on Meiosis (Task 10).
2. The teacher gave procedural instructions for a Mitosis activity and for the Fruit Fly Lab (Task 22--Drosophila Cross), and for written discussion questions over a reading article concerning the Genetics and Environmental Influences on Twins (Task 23).
3. Students worked on a Mitosis activity, and Tasks 22 (Fruit Fly Lab) and 23 (discussion questions concerning an article on the Genetics and Environmental Influences on Twins). All activities were done with partners or in groups.

12/3/84

1. The teacher gave procedural instructions for information to be turned in concerning the Independent Research Project.

(10) *2. The teacher returned graded quizzes on Meiosis (Task 10) to students for correcting. The teacher gave answers to these questions orally.

3. The teacher gave procedural instructions for the Independent Research Project.
4. Students worked on the Fruit Fly Lab (Task 22--Drosophila Cross), the discussion questions on the Genetics and Environmental Influences on Twins (Task 23), and a Meiosis activity.

12/4/84

1. The teacher gave content presentation and procedural instructions concerning Mitosis/Meiosis Test (Task 12).
2. The teacher gave procedural instructions for a Meiosis worksheet (Task 11).

12/5/84

(11) *1. The teacher gave or called on students to give answers to the Meiosis worksheet (Task 11).

2. The teacher gave procedural instructions for Tasks 22 (Drosophila Cross) and 13 (Quiz over textbook reading assignment on Mendelian Genetics).

(12) *3. Students took a test on Mitosis and Meiosis (Task 12).

12/6/84

(13) *1. Students took a quiz over a textbook reading assignment concerning Mendelian Genetics).

2. The teacher discussed the reading assignment concerning the Genetics and Environmental Influences on Twins (Task 23) by calling on students to provide answers to part of the discussion questions.

3. The teacher went over the answers to the Test on Mitosis and Meiosis (Task 12).

4. The teacher gave a content presentation over Genetics Terms and Concepts (Task 14).

12/7/84

(14)* 1. Students took a Quiz on Genetics Terms and Concepts (Task 14).

2. The teacher gave a content presentation on Monohybrid Genetics Problem-solving.

3. The teacher gave procedural instructions for the Fruit Fly Lab (Task 22--Drosophila Cross).

4. Students worked on the Fruit Fly Lab (Task 22).

12/10/84

1. The teacher returned graded products for Independent Research Projects, and Task 11 (worksheet on Meiosis).

2. The teacher returned students' graded papers for the Quiz on Genetics Terms and Concepts and went over the answers briefly (Task 14).

3. The teacher gave content instruction on Monohybrid Problem-solving and Mendel's work.

4. Students did an activity whereby they summarized the information presented in the teacher's previous content presentation (Number 3 above).

5. Students worked in groups correcting their Monohybrid Genetics Problems (Task 15).

12/11/84

1. The teacher gave a content presentation and procedural instructions for the Fruit Fly Lab (Task 22--Drosophila Cross).

(15) *2. Students worked in problem-solving groups on Monohybrid Genetics Problems and the teacher had students write their answers on the blackboard.

3. The teacher gave a content presentation on Incomplete Dominance (Task 18) and Dihybrid Problem-solving (Task 16).

12/12/84

1. The teacher called out students' grades and then returned the products on the Genetics Monohybrid Problems (Task 15).

(16) *2. Students worked in problem-solving groups checking their Dihybrid Genetics Problems from their homework assignment (Task 16).

(17) *3. Students took a Quiz on Dihybrid Genetics Problems (Task 17).

4. The teacher went over the answers to the Quiz on Dihybrid Genetics Problems (Task 17).

5. The teacher gave a content presentation on Genetics Problem-solving Involving Sex-linked Traits (Task 19).

12/13/84

1. The teacher returned graded papers for Dihybrid Genetics Problems done for homework (Task 16) and then gave a content presentation over Genetics Problem-solving as review for a test (Task 18).

(18) *2. Students took a test on the Solving of Genetics Problems (Task 18 --test contained information concerning various genetic concepts as well as Dihybrid and Monohybrid (Incomplete Dominance) problem solving).

3. Students worked on genetics problems involving sex-linked traits (Task 19) after they finished their test (Task 18).

4. The teacher gave a content presentation on the working of Genetics Problems Involving Sex-linked Traits (Task 19).

12/14/84

1. The teacher went over the answers to the Test on Genetics Concepts and Problem Solving (Task 18).

2. The teacher gave procedural instructions for Labs 22 (Drosophia Cross) and 24 (a Genetics Problem-solving Lab).

(19) *3. Students worked in problem-solving groups to check their homework assignments on Genetics Problems Involving Sex-linked Traits (Task 19).

4. Students worked on their Fruit Fly Labs (Task 22--Drosophila Cross).

12/17/84

1. The teacher gave a content presentation and procedural instructions for Lab 18 (Task 24--Genetics Problem-solving Content).

2. The teacher gave procedural instructions for the Fruit Fly Lab (Task 22--Drosophila Cross).
3. Students ked on the Fruit Fly Lab (Task 22--Drosophila Cross), and Lab 18 (Task 24--Genetics Problem-solving Content).

12/18/84

1. The teacher divided students into groups of two to discuss how inheritance patterns could be determined. The teacher then discussed this information with the students in relation to the Fruit Fly Lab (Task 22--Drosophila Cross).
2. The teacher gave a content presentation on Probability (Use of Chi Square) for Statistical Analysis.

12/19/84

1. The teacher gave procedural instructions for the Fruit Fly Lab (Task 22--Drosophila Cross).
2. Students worked on the Fruit Fly Lab (Task 22--Drosophila Cross), Lab 18 (Task 24--Genetics Problem-solving Content), and Chi Square Used for Statistical Analysis (Task 21).
3. The teacher gave procedural instructions for the Independent Research Project.

1/4/85

1. The teacher gave procedural instructions for Task 20 (a Quiz over a textbook reading assignment on Inheritance Patterns).
2. The teacher gave procedural instructions for the Fruit Fly Lab (Task 22--Drosophila Cross).
3. The teacher gave a content presentation concerning the Fruit Fly Lab (Task 22) and Statistical Analysis Involving Probability and the Use of Chi Square.

4. Students worked on the Fruit Fly Lab (Task 22) and Probability problems.

1/7/85

(20) *1. Students took a Quiz over a textbook reading assignment concerning Inheritance Patterns, specifically the trait of eye color (Task 20).

2. The teacher gave procedural instructions for the Independent Research Project, the Genetics Unit Test (Task 25), and the Final Term Exam (Task 26).

3. The teacher went over the answer to the Quiz concerning the Inheritance of the Eye Color Trait (Task 20).

4. The teacher showed a film on Genetic Disorders as students filled out a corresponding worksheet (Task 25).

1/8/85

1. The teacher gave procedural instructions for the Indep[illegible]nt Research Project and the Fruit Fly Lab (Task 22).

2. The teacher gave a content review for the Unit Test (Task 25).

(21) *3. Students worked on Independent Research Projects, the Fruit Fly Lab (Task 22--<u>Drosophila</u> Cross), and Probability problems (Task 21).

1/9/85

1. The teacher reviewed the meaning of Probability Values for Statistical Analysis (Task 26).

(22) *2. Final collection date for Fruit Fly Lab reports.

(23) *3. Final collection date for Task 23.

(24) *4. Final collection date for Task 24.

(25) *5. Students took the Genetics Unit Test (Task 25).

Appendix B

Genetics Task List for Teacher 10, School 7, Period 1, Honors Biology

Genetics Task List for Teacher 10, School 7, Period 1, Honors Biology

1. Worksheet on the Structure/Replication of DNA, "DNA -- Master Molecule" (Homework Assignment)

   Time: 15 minutes

   Sessions: 3 -- 11/14/84, 11/15/84, 11/16/84 (less than 1 minute procedural instruction time spent on 11/12/84)

   Handed in: 11/16/84

2. Lab #14 -- Sex Differences in Drosophila

   Time: 45 minutes

   Sessions: 2 -- 11/12/84, 11/13/84

   Handed in: 11/16/84

3. Quiz Over Textbook Reading Assignment on Protein Synthesis

   Time: 1 hour, 20 minutes*

   Sessions: 3 -- 11/16/84, 11/19/84, 11/20/84

   Handed in: 11/20/84

4. Worksheet on Protein Synthesis (Homework Assignment)

   Time: 28 minutes

   Sessions: 2 -- 11/20/84, 11/21/84

   Handed in: 11/21/84

5. Test on the Structure/Replication/Function of DNA/RNA**

   Time: 2 hours, 29 minutes*

   Sessions: 4 -- 11/14/84, 11/15/84, 11/20/84, 11/21/84

   Handed in: 11/21/84

6. Worksheet on Cell Reproduction

   Time: 44 minutes

   Sessions: 2 -- 11/26/84, 11/27/84

   Handed in: 11/27/84

* Times shared with other tasks
** Major tasks constituting 10% or more of 6-weeks grades

7. Practical Lab Exam -- Distinguishing Male from Female Fruit Flies

Time: 3-7 minutes

Sessions: 2 -- 11/26/84, 11/27/84

Handed in: 11/26/84, 11/27/84

8. Worksheet on Meiosis (Homework Assignment)

Time: 18 minutes

Sessions: 1 -- 11/29/84

Handed in: Unknown

9. Lab #16 -- Observation of Mitosis Stages in the Onion Root Tip

Time: 1 hour, 32 minutes

Sessions: 2 -- 11/27/84, 11/28/84

Handed in: 11/28/84

10. Quiz on Chromosomes and Meiosis/Mitosis

Time: 13 minutes

Sessions: 2 -- 11/30/84, 12/3/84

Handed in: 12/3/84

11. Worksheet on Meiosis (Homework Assignment)

Time: 21 minutes

Sessions: 2 -- 12/4/84, 12/5/84

Handed in: 12/5/84

12. Test on Cell Division -- Mitosis/Meiosis**

Time: 46 minutes

Sessions: 1 -- 12/5/84

Handed in: 12/5/84

* Times shared with other tasks
** Major tasks constituting 10% or more of 6-weeks grades

13. Quiz on Genetics Terminology

Time: 11 minutes

Sessions: 1 -- 12/6/84

Handed in: 12/6/84

14. Quiz on Genetics Terms and Concepts

Time: 18 minutes

Sessions: 2 -- 12/6/84, 12/7/84

Handed in: 12/7/84

15. Monohybrid Genetics Problems (Homework Assignment)

Time: 1 hour, 21 minutes

Sessions: 3 -- 12/7/84, 12/10/84, 12/11/84

Handed in: 12/11/84

16. Dihybrid Genetics Problems (Homework Assignment)

Time: 35 minutes

Sessions: 2 -- 12/11/84, 12/12/84

Handed in: 12/12/84

17. Quiz on Dihybrid Genetics Problems

Time:

Sessions: 1 -- 12/12/84

Handed in: 12/12/84

18. Test on Mono and Dihybrid Genetics Problems and Related Content**

Time: 37 minutes

Sessions: 2 -- 12/12/84, 12/13/84

Handed in: 12/13/84

* Times shared with other tasks
** Major tasks constituting 10% or more of 6-weeks grades

19. Monohybrid Genetics Problems Involving Sex-linked Traits (Homework Assignment)

Time: 47 minutes

Sessions: 3 -- 12/12/84, 12/13/84, 12/14/84

Handed in: 12/14/84

20. Quiz over Textbook Reading Assignment Concerning Genetics in Human Populations

Time: 8 minutes

Sessions: 2 -- 1/4/85, 1/7/85

Handed in: 1/7/85

21. Probability Problems -- Chi Square Analysis of Experimental Results of Genetic Crosses (Homework Assignment)

Time: 2 hours, 13 minutes*

Sessions: 4 -- 12/18/84, 12/19/84, 1/4/85, 1/8/85

Handed in: 12/19/84, 1/8/85 (Products redone and handed in a second time.)

22. Lab #15 -- Determination of Inheritance Patterns for Specific Traits in the Fruit Fly, "Drosophila Cross"**

Time: 6 hours, 55 minutes*

Sessions: 18 -- 8/28/84, 11/13/84, 11/14/84, 11/16/84, 11/19/84, 11/21/84, 11/26/84, 11/30/84, 12/3/84, 12/5/84, 12/7/84, 12/11/84, 12/14/84, 12/17/84, 12/18/84, 12/19/84, 1/4/85, 1/8/85

Handed in: 11/15/84, 11/27/84, 12/14/84, 1/9/84

* Times red with other tasks
** Major tasks constituting 10% or more of 6-weeks grades

23. Written Discussion Questions Over a Reading Article, "Twins Reunited," Concerning the Genetics and Environmental Influences on Twins

Time: 1 hour, 31 minutes*

Sessions: 3 -- 11/30/84, 12/3/84, 12/6/84

Handed in: 11/20/84 - 1/9/85

24. Lab #18 -- Determination of Students' Genotypes for a Variety of Characteristics

Time: 1 hour, 19 minutes*

Sessions: 3 -- 12/14/84, 12/17/84, 12/19/84

Handed in: 1/9/85

25. Major Multiple Choice/Short Answer Test over the Genetics Unit Content**

Time: 1 hour, 43 minutes

Sessions: 3 -- 1/7/85, 1/8/85, 1/9/85

Handed in: 1/9/85

26. Final Multiple Choice Semester Exam**

Time: Unknown

Sessions: 1 -- 1/9/85

Handed in: 1/9/85

* Times shared with other tasks

** Major tasks constituting 10% or more of 6-weeks grades

Appendix C

Task Analysis for Teacher 10, School 7, Period 1, Honors Biology

Task 22, "*Drosophia* Cross," Determination of Inheritance

Patterns for Specific Traits in the Fruit Fly

Task Analysis for Teacher 10, School 7, Period 1, Honors Biology

Description: Task 22 -- "Drosophila Cross", Determination of Inheritance Patterns for Specific Traits in the Fruit Fly

The Assignment:

This assignment involved the mating of two generations of fruit flies with one particular mutant trait variation. Students were allowed to chose one from four specific mutations available including: 1) black (refers to body color), 2) sepia (refers to eye color), 3) white (refers to eye color), or 4) vestigial (refers to the body structure). They were to have worked with partners to set up their crosses, recorded dates and procedures followed, and observations regarding the numbers and appearance of adult and larval flies, and then to have determined probable inheritance patterns for their particular mutation according to experimental results obtained. Next, assuming a particular inheritance pattern, they were to have determined the expected geno- and phenotypic results of such a cross using the Punnett Square method and then to have analyzed their results by use of Chi Square, determining the fit of experimental with expected results. Specific requirements for carrying out the lab and recording information in a written report are given below.

1. Students were to clip off at least four pages in their lab books to be used for this lab report. Students were told that they could use two pages if they preferred, using the back and front of each page. (The teacher announced this in response to a student's public question.)
2. Students were to observe flies with each mutation (black, sepia,

white, and vestigial) and determine which specific mutant trait they wanted to use for their cross. Students were to work with a partner. Flies were to have been anesthetized in small containers of ether fumes and then gently shaken out onto 3x5 white index cards to be observed under the dissecting microscopes. (See Task Analysis for Task 2 for anesthetizing procedure.)

3 Students were to add three mutant males of their choice (all with the same mutation) to a vial containing three wild type (normal for the particular trait under consideration) virgin females. (Students were to be careful never to knock food mixtures on top of flies when transferring them from vial to vial, or from vials to etherizers.)

4. Vials were then to have been labeled with students' names, date, and a description of their particular cross.

5. Students were to record the number of wild type and mutant flies found in the F_1 generation. They were told to look at between 15-20 flies per generation (the teacher did not give this specific information to students until 12/7/84, 3-4 weeks after students began work on the lab).

6. Students were to release the parent generation flies from the vials after they had mated. (Approximately 1 week later.)

7. They were to record their observations concerning the numbers and appearance of the various larval stages and adult flies once they had hatched and then set up a second generation cross with the F_1 flies, putting at least three males and three females into a second vial of food, clearly labeling them with the students' names, description of the cross, and the date. They were to rubber band this vial together with the original one and retain both cultures.

8. They were to have removed the flies from the second generation cross after approximately 1 week, or when they were certain that the cross was going well (flies had mated and larvae developed).

9. When the F_2 generation flies had hatched into adults, students were to count and classify them as to phenotype and sex.

10. All observations were to have been recorded in lab books.

11. Dead or left over flies were to have been washed down the sink or released outside.

12. All crosses were to have been checked for eggs, larvae, and dead flies during each observation session. Again, all information was to be recorded in students' lab books.

13. If necessary adult flies had died, students were to have put a note on the vial with a rubber band, requesting the teacher to replace the flies, indicating the particular type (wild/mutant) that needed to be replaced. (The teacher gave this information orally to the students on 11/16/84.) Students were to record that their flies died if they had, in their lab books.

14. All vials and materials were to have been cleaned up after students had completed the lab.

15. Information to have been included in the lab writeups was as follows:

    a. title (as given on handout "Drosophila Cross")

    b. purpose (statement of purpose of the lab)

    c. name of lab partner

    d. date the original cross was set up

    e. description of the cross (e.g., + ♀ x b♂ ; + represents wild type female, b represents black bodies male mutant.)

f. description of how your mutant differs from the wild type fly

g. observations of egg and larval stages of the F_1 generation, including counts of the number of male/female flies of the wild/mutant type resulting in this generation (this includes comments concerning flies that have died or have been replaced)

h. carry out procedures d through g for crosses with the F_1 generation and then for the F_2 generation

i. Students were to determine and record the pattern of inheritance that pertained to the inheritance of the trait observed in their cross according to their experimental results. According to this pattern, students were then to determine expected phenotypic ratios for such a cross and then do a Chi Square test determining the fit of observed with expected results. Students were then to give an interpretation of the resulting probability value.

Specific instructions as given on lab handouts were as follows:

> Answer the following five questions: (1) Was the gene that caused the mutation you followed dominant or recessive? Autosomal or sex-linked? Explain your answer. (2) The original parents you used were homozygous for the "normal" trait and for the mutant trait. Assign letters for the pair of genes involved in your cross. Use a capital letter for the dominant gene and a small letter for the recessive gene. Show a paper cross. Give the genotype of the original parents. Then, with a Punnett Square, show what happened. Show both generations. (3) Run a Chi Square test, using your data, to test your hypothesis. Tell what your probability answer means. (4) How close do your results match what paper cross shows was expected? If your results are not close to the expected, how do you account for this? (5) Evaluate the lab. Was the lab worth doing? What problems did you have with this lab? How could the lab have been improved?

<u>Time</u>:

8/28/84 1 minute procedural instruction time.

11/13/84 16 minutes procedural and content instruction time

30 minutes student work time

11/14/84 4 minutes procedural and content instruction time

11/16/84 4 minutes procedural instruction time

9 minutes student work time

11/19/84 11 minutes procedural instruction time

11/21/84 4 minutes procedural instruction time

*As much as 17 minutes of time counted as student work time for Task 10 could have been used by students to work on the Drosophila Cross.

11/26/84 9 minutes student work time

11/30/84 4 minutes procedural instruction time

**42 minutes student work time

12/3/84 3 minutes procedural instruction time

**41 minutes student work time

12/5/84 1 minute procedural instruction time

12/7/84 2 minutes procedural instruction time

25 minutes student work time

12/11/84 8 minutes procedural and content instruction time

12/14/84 1 minute procedural instruction time

13 minutes student work time

12/17/84 1 minute procedural instruction time

*48 minutes student work time (41 of the 48 minutes in this work time is shared with lab #18, Task 24. Students worked on both of these tasks during the work period.)

12/18/84 *26 minutes procedural and content instruction time

12/19/84 5 minutes procedural instruction time

1/4/85 *30 minutes content instruction time (This content instruction time was shared with Task 21, Chi Square problems to have been re-done.)

3 minutes transition time

*19 minutes student work time (Work time shared with Task 22)

1/8/85 3 minutes procedural instruction time

*36 minutes student work time (shared with time spent working on the Independent Research Project, and Task 21, Chi square problems)

*Note: These are times when the students worked on more than one task during a class period, or the teacher discussed more than one task during a content presentation. However, the times spent on each individual task during these work sessions could not be distinguished from one another.

**Note: These times refer to student work periods or teacher content presentations which involved more than one task. Half of the students worked on this task (Task 22, the Fruit Fly Lab) while the other half worked on a mitosis activity and/or Task 23 on 11/30. The other half of the class worked on Task 22 while those who had worked on Task 22 on 11/30, now worked on the mitosis activity and/or Task 23 on 12/3.)

Related Sessions:

Students had received content presentations and worked on previous tasks containing content pertinent to the Fruit Fly Lab. These included Tasks 2, 7, 8, 10, and 11-25 on 11/12, 11/13, 11/26-11/30, 12/3-12/7, 12/10-12/13, 12/17, 12/19, 1/4, 1/7, and 1/8.

Prompts and Resources:

1. The teacher explained the lab procedure to be followed and then demonstrated the method for anesthetizing of the flies on 11/12.

2. On 11/13 the teacher demonstrated the technique for transferring mutant male flies into vials containing the wild type females.
3. On 11/12 the teacher told the students the title and purpose to be given for the lab writeup. The teacher also defined relevant terminology during this time (on 11/13).
4. On 11/13 the teacher told students that the black mutant was an indication of some color change from the wild as was the sepia mutant. The teacher also explained that the term, "vestigial," referred to a non-functioning remnant. (Students were required to describe their particular mutant characteristic in their lab writeups.)
5. The teacher had numerous private contacts with students in their groups on 11/13. The teacher checked students' crosses and vials for appropriate labels. However, the teacher later indicated in an interview on 3/10/85 that a number of students had inappropriately identified their flies at the beginning of this lab.
6. Students worked with partners, sharing their observations with each other and students in other groups.
7. On 11/14 a student asked a public question. The teacher then had this student provide the answer to what was one of the lab questions (what the white mutant referred to -- eye color). Students had been previously told they needed to figure out what the mutants stood for for themselves. The teacher also told students what the mutant "sepia" referred to on 11/30.
8. The teacher told one group of students that they needed to work with

another group because their flies were not any good (apparently indicating that their crosses were inappropriate or that their flies had died).

9. The teacher had students orally describe the various larval stages of the fruit fly on 11/21. The teacher told the students that if there were no eggs or larvae in their crosses, then their crosses were not going well and that they needed to check with her. On 11/26 the teacher identified various larval stages for some of the students' specimens.
10. The teacher checked one student's work repeatedly, telling him each time what additional information he needed to record in his lab book.
11. The teacher repeated procedural information, writing it on the board again on 11/30 and was observed helping individual students before or after class on this date also.
12. The teacher had the lab assistant (or management) students in the classroom help students during work periods, helping to identify various mutants and possibly larval stages.
13. On 11/30 the teacher put a chart on the board, telling students that they should record their counts on their mutant and wild flies in this form.
14. On 12/5 the teacher told students who had not yet done so that they must set up their second generation fruit fly crosses.
15. On 12/7 the teacher gave some students a vial of vestigial flies and identified them for the students, as these students had apparently misidentified these flies when they began the work.

16. On 12/11 the teacher told the students that they should assume that each of the phenotypes were homozygous for that trait in the parental generation (red eyes, sepia eyes, yellow-bodied, etc.).
17. On 12/7 the teacher identified the sex of some of the flies for students.
18. On 1/4 the teacher worked a sample cross and then analyzed the results with the Chi square method on the blackboard. The teacher had students provide answers on how their own crosses fit various inheritance patterns at this time. The teacher provided three patterns on the board and told students that all of their results would fit one of these three patterns.
19. Students had done a previous assignment (Task 21) working Chi square problems.
20. On 1/24 the teacher confirmed expected probability values and inheritance patterns for some students who requested this.
21. The teacher told one student that he didn't have enough flies to see what his pattern was, and so he should mention this in his writeup. The teacher then asked for results from another group's observations, wanting to give this student some numbers to work out expected probability values. No one had these particular traits and so the teacher just gave this student some numbers to work with (the teacher may possibly have given a number of other students numbers to work with for various reasons including insufficient numbers of offspring to determine inheritance patterns or inappropriate results which did not fit either of the three patterns given).
22. Students had done a previous task (Task 2) where they observed the

differences between male and female fruit flies. This task took place on 11/12 and 11/13. During the time students spent working on the Drosophila Cross, they had also worked on a number of previous tasks containing content relevant to this lab. These included Tasks 2, 7, 8, 10, 11-19, 21, and 24 on 11/12, 11/13, 11/28, 11/29, 11/30, 12/3, 12/4, 12/5, 12/6, 12/7, 12/10, 12/11, 12/12, 12/13, 12/14, 12/17, 12/18, 12/19, 1/4.

23. On 1/9 the teacher confirmed the accuracy of a probability value for a student who asked if his answer was correct. The teacher also explained what this value meant to the student at that time. (Students were required to do this for their lab writeups.)

Accountability:

1. Students' work as it was completed to date was collected on 11/16. The teacher had indicated to students that she would be keeping track of their recordkeeping as they proceeded. She indicated that students would lose points during these times if they were not keeping accurate records. The teacher returned these products to students on 11/19, telling students that from now on she would subtract points for not listing the number of fruit flies observed. Apparently the teacher did not subtract points for this during this collection period. The teacher had either put a check or an OK on student papers, indicating that their work to date was acceptable. Papers that were missing information were frequently marked "incomplete records!" and the teacher tended to ask a number of students how many male and female wild type/mutant type flies they had used in their crosses as a number of students had omitted this information. The teacher did not assign points to

products at this time, and it is not certain how, or if, this work affected students' final grades for their products. At least three students did not appear to have turned in any products by this date.

2. The teacher again collected students' lab books to check their recordkeeping on 12/14. Again, the teacher wrote comments in the students' lab books, at times telling students that they needed to see her about their work. The teacher commented on some of the papers that students needed to write their observations in their own words. Again, the teacher did not assign any point values during this checking time, and it is not certain if or how papers collected on this date affected students' final grade for the project.
3. On 11/19 the teacher told students that their recordkeeping would be worth a total of 50 points for this task. The lab was worth 100 of the 900 points given for the 6-weeks grading term.
4. The teacher told students that their grade would be based on both their recordkeeping and the accuracy of their writeup. The teacher told students this on 1/4.
5. Students were told that they would lose points on their lab writeups if they did not clean out their vials after finishing with the fruit flies. The teacher told students this on 12/19.
6. The teacher told one student after class that he would receive extra credit for figuring out what went wrong with his cross (apparently this student ended up with inappropriate results). The observer believes that although the teacher indicated this was to be done for extra credit on 1/9 to this student, she had originally told students who had ended up with what the teacher had identified as

inappropriate results that they must explain what went wrong with their cross as a part of their lab writeup for regular credit.

7. Students were originally to have handed in their completed writeups by 1/7/85, however, as one student pointed out to the teacher that they needed to be using their lab books to finish their work on their Independent Research Project, they would be unable to hand their labs in by the date requested. The teacher agreed with this, and told students that they would have an additional time to complete their products, which were to be handed in on 1/9.
8. Eight students received grades of 95 to 100; two students received grades of 92; one student received a grade of 90; two students received grades of 85; two students received grades of 80; two students received grades of 75-78; two students received the grade of 70; and one student received a grade of 60.

How It Went:

The teacher introduced the assignment on 8/28, the second day of class. The teacher told students that this was going to be a long-term lab and then gave a very brief procedural overview for the experimental procedure. The teacher gave this information orally only at this time, spending only 1 minute on the topic. On 11/12 the teacher gave the students a handout which contained the specific lab procedure to be used for a related lab, Lab 14, which was an observation lab during which students were to observe and record differences between male and female fruit flies. The teacher went over this handout containing procedures and then gave a demonstration on anesthetizing flies. Students observed the flies and distinctions between the two sexes during a work period on 11/12.

On 11/13 the teacher identified this task again as a major assignment. The teacher then gave both procedural and content instructions for the lab, and then assigned students to work with partners. Students were given handouts containing the exact procedure to be followed for this lab. Students then worked with their partners, setting up their crosses. Students had formed their own groups (choosing their own partners) the day before when they worked on Lab 14. There was some off-task behavior in these groups, and the teacher made a couple of changes in partners as they began work on this task. Students worked together, sharing information as they interspersed observation/work with visitation. The teacher moved from table to table during this time, supposedly checking students' crosses to make sure that students had appropriately identified and labeled their vials of flies. Lab assistant (or management) students were in the classroom during most of the student work times, available to students who had questions.

On 11/14 the teacher had students check to see if they had been recording the appropriate information in their lab books. The teacher wrote the required information on the board and told the students that she would be collecting this work at the beginning of the period on the following day, 11/15. The teacher answered public student questions at this time, providing content information, some of which students had been previously told that they needed to provide for themselves, for example, what the term, "white," referred to in the mutant fly. Students worked on their labs in class on 11/15, and the teacher collected their work on 11/16.

The teacher returned students' products on 11/19 and told students that from now on she would subtract points if students did not list the number of fruit flies that they used to begin the cross. The teacher told students at that time that this task was worth 100 points, and that 50 of those points would be for recordkeeping, and the other 50 points for the accuracy of their writeup. The teacher appeared only to mark checks or OK in some of the students' lab books for the work they had done so far, indicating on other students' work that their work was incomplete or that parts of the information provided was inaccurate (e.g., inaccurate descriptions given for the particular mutation used). It is not known how or if points were subtracted from students' final products for the checking that the teacher did at this time. The teacher also told students that they must make records in their lab book of any fruit flies they were using that had died. The teacher appeared to indicate on a few student papers that these products must be re-done because they were inaccurate.

On 11/20 before class began, the teacher told some students that they needed to begin new crosses because theirs were not progressing properly. The teacher wrote the names of these students on the blackboard and told the students they needed to begin their new crosses either at lunch or before school. At least four groups of students (eight students) had problems with fruit flies that had died. The teacher told one group of students at this time that they could work with another group rather than restarting their cross, although it is not certain why the teacher did not make these students begin a new cross as she did with the others. There was some indication on this date that students were incorrectly identifying their mutant flies, as the teacher talked to students in groups, telling them that they were using a particular mutant, one different than that identified by the students.

On 11/21 the teacher gave procedural information for lab records and told students that these were to be handed in on 11/27. The teacher had students provide descriptions of what they were looking for in their observations (larval stages, etc.). Students used some class time after completing another task (Task 5, a test) on this date to continue work on the Fruit Fly Lab. On 11/26 the teacher told students to look at their crosses again and to be sure to record in their lab books anything they saw and to let out any adult flies that needed to be released. The teacher identified larval stages for some students and asked to see one student's work that day. Some students appeared to sit and copy from their partner's. There was a lot of student visiting during the work time that day. It is not known if student products were actually checked by the teacher on 11/27 or not.

On 11/29 the teacher told the students that they were to continue reading the directions given in their <u>Drosophila</u> Cross handout, so that they knew what they would be doing in class on the lab the next day, on 11/30. On 11/30, the teacher had the lab assistant (management) students set up microscopes and materials again. (These students were from other classes taught by Teacher 10, in which students were learning how to manage laboratories. These students received credit for their courses for helping the teacher set up labs in her other classes.) The teacher was observed helping students with crosses both before and after class on 11/30, apparently offering procedural assistance.

The teacher again gave procedural instructions on 11/30 and then described the sepia mutant, something that students were originally told they needed to do for themselves. Half of the students in the class worked on the lab this day, while the other half worked on alternate tasks, a mitosis activity and Task 23. Lab assistants moved around the room, helping students with their work. The teacher also checked students' work at this time, walking around the room and looking at the work as they recorded their observations. The teacher told some of the students that they only needed to count 30 flies (the teacher later changed this to 15-20 flies). The teacher also put a chart form on the board and told students that this was the form they could use to record the numbers and types of fruit flies that resulted. The teacher told students that because some were misidentifying their mutant/wild flies and for other reasons, students were appearing to show numbers that were not consistent with the results they should have been obtaining from their particular crosses. She said that she was going to let them continue with their work, hoping that they would learn something from having to figure out what it was that they did wrong with their crosses after she presented information about how their results should have come out.

On 12/3 the teacher had one student begin his fruit fly cross over. The teacher again indicated that a number of students (at least five) had already set up new crosses. Again, the teacher told students that some of them were misidentifying their mutants. The teacher gave students a new handout at this time, containing, again, the procedures used to carry out the lab and for recording information in their lab writeups. This handout was more complete than the one given to students previously on 11/13. (See attached handout.) The teacher checked several students' crosses on this date, asking students what crosses they were doing, and then apparently looking at their results to see if they corresponded to those crosses. The teacher told some of the students in the class at this time that they must have misidentified their flies when they started the lab, again telling a number of the students that they needed to re-start their crosses today.

On 12/4 the teacher told the observer that some of the crosses had not been going well and that apparently she felt the lab assistants had misidentified flies for students when they originally began their crosses. Students were to have identified the flies themselves, although they were told they could request assistance from lab helpers. The teacher told the observer that she was going to ask students to explain what could possibly have happened with their crosses for those who would not be able to find an appropriate pattern for their results. On 12/5 the teacher again gave students procedural instructions and called out the names of student who had not yet set up their second generation crosses. The teacher told these students that they must begin their second generation crosses today. The teacher told students that she felt certain that some of the food had molded in the vials and that could have been part of the reason that the fruit flies were dying for some of the students. The teacher said that she had prepared new sterilized food mixtures for the students to use and that she had forgotten to sterilize the mixtures when she originally began the lab.

On 12/7 students worked on the lab, interspersing work with socializing and playing. The teacher continued asking students if they had set up their second generation crosses at this time, and apparently found that one student had not yet done so. The teacher was upset with this student and told her that if she didn't know what to do, she was always to ask the teacher and not just leave her work. Again, the teacher appeared to be looking at students' work, moving from table to table as students worked on the lab.

On 12/7 the teacher gave additional procedural instructions, telling students that they would be meeting later in the week with someone else in the class who had done the same cross that they had, in order to discuss their results. The teacher said at students were to figure out how the mutation they used was inherited, that is, which of the three inheritance patterns the teacher presented best fit as an explanation for their results. The teacher told the students that they should have been able to view enough of the F_1 generation flies to determine the inheritance pattern by this time. The teacher then told the students that they needed only to look at between 15 to 20, rather than the original 30 flies. The teacher also told the students that they should assume each of the phenotypes observed were homozygous for that particular trait in the parent generations. The teacher then appeared to tell students that all of the people in the class who worked on a particular mutant cross would discuss their results with all students in the class who had done the same cross. The teacher told students that if they did not get the results that they expected, then they should explain why they got the results that they did.

On 12/16 the teacher gave procedural instructions for the day and students then worked on the lab. The teacher collected students' lab books at the end of the period to check their recordkeeping. Again, the teacher looked at students' work, indicating where their information was incomplete or inaccurate However, the teacher did not seem to assign points to any of the products, and it is not known how or if checking contributed to the students' final grades for the project although products contained corrective feedback and suggestions for modifications.

On 12/17 the teacher told students that they needed to count up their F_2 generation flies if they had not yet done so. Some students worked on the lab on this date. Lab assistants provided procedural assistance. Students interspersed working with socializing. The teacher helped some students by giving them procedural assistance or by identifying the sex of the flies they were observing.

On 12/18 the teacher divided the class into pairs and then wrote each of the three inheritance patterns pertinent to work with the fruit flies on the blackboard. Students were asked to talk among themselves to determine how they could tell if each of the three patterns were taking place. After students briefly discussed this content with one another, the teacher discussed ways of determining if a trait was each of the three patterns given by calling on students for answers. The teacher wrote this information on the blackboard, indicating that the autosomal dominant pattern would show up in each generation, that it could not skip a generation. In other words, it would show up in the F_1. The teacher indicated that the characteristic could skip generations only if it was an autosomal recessive pattern. The teacher also wrote on the board that there would be no differences in the trait between the males and females. The teacher also wrote on the board that a trait which followed the sex-linked recessive pattern would show up differently in males and females. The teacher told students that none had a pattern which would fit under the sex-linked dominant category.

The teacher then went on to ask students what could have happened if none of these patterns fit the results they obtained. The students provided a number of examples, including late removal of adult flies, misidentification of males and females, nonvirgin females used to begin with. The teacher had students publicly provide examples of things that could have gone wrong with their crosses when she had originally indicated that students were to figure this out for themselves. The teacher did say that if their results did not fit one of these patterns, then they should get together with other students who did the same cross and look at their data to determine the pattern for that cross. If students were not able to figure out the appropriate pattern still, they were to go to the teacher, and she would provide them with numbers which would appropriately fit one of the patterns. Students would use these numbers to determine which pattern was relevant.

On 12/19 the teacher told the students that they must count the F_2 generation flies, and that they could not wait until after vacation time, as the students' Christmas vacation time began on the following day and lasted through 1/3. The teacher told the students that if the flies in their second generation were not yet ready to count, then they must take their fruit flies home with them. The teacher told students that this would be a problem for them because it was likely that they did not have microscopes at home. The teacher offered no solution to this problem. Three students indicated that they were going to be taking their fruit flies home over vacation time.

The teacher told the students that after they completed the lab, they were to either release their flies outside or wash them down the drain. She said that the students needed to clean out their vials and that they would lose points from the lab if they did not do so. All students were to have the teacher sign their lab writeups when they finished cleaning up. Students continued working on their labs on this day. The teacher walked around the room telling students that she was going to look at their work and tell them if their results were good enough to show a pattern yet or not. The teacher told the students that they must go ahead and figure out how their characteristics were inherited and then run a Chi square test on the results. The teacher told the observer on this date that she was pleased with the way the data had turned out and that all but two groups of students had gotten fairly good patterns from their results.

On 1/4 the teacher told students that this was the last day for recording information from their fruit fly crosses, although the observer believes that this date would have been too late for students to count flies, as a third generation would have been started already. The teacher reminded students that their grade would be based on recordkeeping and the accuracy of their writeup. The teacher read questions to be answered on the lab writeup to students, and students were given a handout containing these questions. The teacher told the students that they could not run a Chi square test on their results until they knew if their trait was sex-linked recessive, autosomal dominant, or recessive. The teacher also drew attention to the fact that one of the questions to be answered for the lab was an evaluation. Students were to tell if they felt the lab was worth doing, what problems they had with the lab, and how they felt the lab could have been improved.

The teacher indicated that students' work should be handed in on 1/7. However, one student drew attention to the fact that students needed their lab books to complete their Independent Research Projects which were not due until 1/9. The teacher agreed that as students needed their lab books to complete this task, that they would not be required to hand in their Fruit Fly Labs until 1/9.

On 1/4 the teacher worked some genetics problems on the board, using fruit flies, determining Chi square and probability values. Students worked on their labs after this content presentation. The teacher assisted students during the work time, providing them with appropriate result sample numbers, and confirming correct inheritance patterns and expected probability values when requested.

The teacher gave procedural instructions again on 1/8, reviewing information required for the lab writeup, including records, results, and answers to questions on the handout (see attached handout). The teacher reminded students that they were to calculate their Chi square and probability values and that they were to interpret these values, in terms of the support it lent to their hypothesis of how their particular mutation was inherited. One student requested how long the writeup was to be, and the teacher said that it did not need to be very long, but did not provide any specific information here. The teacher told the students that the important thing from this lab was having had the experience of performing the experiment in the first place. Students worked on their fruit fly writeups and other tasks (an independent research project and Task 21) on this date. Students helped one another working out their problems and interpreting their data. The teacher also appeared to assist students with this work.

On 1/9 the teacher also confirmed a probability value as correct for one student, when requested. The teacher also told the student what her probability value meant, something students had originally been told they needed to do for themselves. Once again, it appears that the teacher provided information which reduced the cognitive demands of the task. The teacher also mentioned to one student after class on this date that he would get extra credit for telling what had gone wrong with his cross. Again, this was a requirement the teacher had originally indicated all students with inappropriate results were to have done.

According to records of student products collected by the observer through 1/17/85, four students had not handed in work and received zeros in the teacher's grade book. Eight students received grades of 95-98; two students received a grade of 92; one student received a grade of 90; two students received grades of 85; two students received grades of 80; one student received a grade of 78; one student received a grade of 75; two students received grades of 70; and one student received a grade of 60 (out of 100 total points).

All students titled their labs, "Drosophila Cross," as given on the instruction handout. Most students also gave as the purpose that which the teacher gave orally in class, "To find out how a mutant gene is inherited." Most students then provided a description of their cross, telling the mutant type used and the number of flies mated. Most students followed this with 7 to 10 dates containing observations concerning a variety of things, including: (1) evidence of mating -- eggs and larvae (numbers/appearance/positions); (2) dead flies found and dates when crosses were started and restarted; (3) dates when adult flies were released; (4) dates when food mixtures were replaced; (5) the number of wild and mutant male and female flies counted (commonly in chart form). Students counted their flies in the F_1 and then their F_2 generations and recorded this information in chart form, the same as shown by the teacher on the board. Students followed this by providing explanations of the inheritance patterns they felt were in effect for the particular traits they were looking at, and then giving expected genotypic and phenotypic ratios (using the Punnett Squares) for a cross involving the particular inheritance pattern they had identified. This was followed by a Chi Square analysis of the results of the F_2 generation. Students were to give the probability value from their Chi Square test and then give explanations for the value given.

At least one-fourth of the students who did the work indicated on their papers that they had re-done their crosses because they had inappropriate results or dead flies, and at least as many students indicated that they had used other students' or teacher-provided numbers to do their Punnett Square and Chi Square analyses.

Two of the 20 students' products seen gave no indication of the inheritance pattern in effect for their trait, while another five to six students incorrectly identified the inheritance pattern for their trait, although a couple of students correctly identified patterns for the results they had recorded (results possibly in error or the numbers recorded were insufficient to demonstrate the appropriate pattern). Twelve of the students did appropriately identify the inheritance pattern for their mutation, giving appropriate explanations for the patterns identified.

Although most students correctly worked their Chi square tests on their experimental results (or results provided by the teacher), at least one-fourth of the students who did the work did not provide or provided inappropriate explanations of the probability values obtained. A majority of the rest of the students provided simplified explanations which in fact had very little meaning. These explanations were, however, stated in terms previously used by the teacher in explaining the meaning of Chi square tests and resulting values. The teacher's initial explanations for this analysis were fairly clear; however, she simplified these to a point where they had very little meaning. Students seemed to have repeated these rather non-meaningful explanations in their lab writeups many simplifying them even further (all were accepted by the teacher as correct).

The teacher did not indicate how many points she subtracted for various problems with students' papers other than to indicate that students who did not answer any of the lab questions lost 20 points, that students who did not provide Punnett square analyses lost 10 points, and that students who did not do Chi square testing lost 10 points. Teacher comments on these papers referred to unclear explanations or calculations, incomplete or missing descriptions of mutations or observations, omissions of explanations for inheritance patterns provided, inappropriate inheritance patterns provided according to the data given, and incomplete records.

Students who did evaluations for the lab generally indicated that they felt that the lab was worth doing and that they liked it, although approximately one-fourth of the students indicated that they had needed more time to efficiently do the work. Student complaints about the lab concerned the lack of a lab partner at times, lab partners who were not useful, procedural problems (difficulties transferring flies from vial to vial, dead flies, bad food), not enough help given with recordkeeping, and insufficient time. Student suggestions for improving the lab included increased time, additional help with recordkeeping, and procedural assistance.

Of the nine students interviewed in this class, all but one described this lab as more difficult than other labs done in this class, giving procedural difficulties, Chi Square testing, and the fact that it was a long term project as factors which made this assignment more difficult. Approximately half of these students did not appear to understand the inheritance patterns operating in the fruit fly cross they had done according to their attempted explanations to this question in the student interviews. In addition, at least one-third of these students were not able to explain, or provide accurate explanations for the Chi square or probability values obtained from the statistical analysis of experimental results.

The teacher indicated in an interview that she felt students had utilized the lab assistants' help to a greater degree than she would have liked. The teacher also commented that these lab assistants sometimes incorrectly identified flies.

Cognitive Operations:

Procedural and Comprehension-level Operations required, although the extent of the cognitive processing required to successfully complete the task was limited by teacher prompting and accountability aspects of the system.

PMW 4/3/85

JKC 5/23/85

GENETICS: DROSOPHILA CROSS

Each person must set up and follow through a cross for two generations. You may choose the particular mutant you want to work with; each person within a table group should work with a different mutant. The deadline for setting up your cross is ________________.

Collecting virgins. In general, use wild type females; these must be virgins. One way to collect them is to dump out all adults from the stock vial, and then you may use any females which have been hatched off within a 4-6 hour period of time. For example, you could dump out all adults at 8:00 a.m. and then collect females to use during your class period or lunch hour. Very young adults of both sexes have a greyish wad of tissue in their abdomens. They are very light colored when they first hatch, so this is quite apparent. The grey plug seems to change position, going toward their posterior ends. It disappears when they are several hours old. If you see this, you may safely use those flies as virgins.

Setting up the Cross

a. Put 3 virgin wild females into freshly prepared food. Add 3 mutant males of your choice.

b. Label the vial clearly with: 1) your name; 2) a shorthand description of the cross. Example: + ♀ X e♂
and 3) the date.

c. One week later, or as soon as you see that the cross is going very well, dump out the parents.

d. When the F_1 flies emerge, count and classify them as to sex and phenotype. (50)

e. Set up your second generation cross of F_1 x F_2. Put at least 3 males and 3 females into a second vial of food. Label clearly with name, description of cross, and the date. Rubber band this vial to your other vial. Retain both cultures.

f. Remove the parents of your second generation cross after one week or when you are sure the cross is going very well.

g. When the F_2's emerge, count and classify them as to phenotype and sex. Aim for 100 F_2's.

DROSOPHILA CROSS,

Records

Set aside 4-6 pages in your lab notebook. Use paper clips to set this section apart. Record dates and a complete description of every thing you do which pertains to the cross. Describe what you observe. Records of your original counts of offspring must be included; it is the original records which have validity, not copied records.

Example:

10/18 I placed 3 wild females and 3 bar males in a vial of fresh food.

10/19 3 males were dead; their wings were stuck in food. I put in 2 more males. One female escaped.

10/23 I observed 2nd stage larvae in the food. Cross seems to be going well.

10/28 All adults were dumped out. There are 3rd stage larvae and pupas. Food seems soupy, so I added a large pinch of dry food.

10/31 F_1's examined.

	wild ♀	wild ♂	bar ♀	bar ♂
10/31	卌 III	I	III	
11/2	卌 卌 III		I	

Note: This form should be used for all scoring and counting of flies. Total the columns when you complete the scoring.

11/2 Took 3 F_1 females and 3 F_1 males, and set up the second cross.

etc.

Analysis:

1. State how you think the mutant gene is inherited, based on your data. Your choices are: a) autosomal dominant; B) autosomal recessive; c) sex-linked dominant; d) sex-linked recessive
2. State the evidence of your choice.
3. Do a paper cross. This means that you set your cross up, using capital and small letters, punnett squares, etc. to show what you think happened.
4. Do statistical analysis, using chi square, to find out how well your data fit your hypothesis of how the mutant allele is being inherited.

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Evaluation: Describe your problems, your reactions to the work, etc.

How this Investigation will be graded:

	Points
Records	60
Analysis of cross (includes paper cross)	15
Statistical analysis (Chi square)	15
Evaluation of cross	10
	100

Note: Failure to clean up vials, etc. will result in deduction of 10 points.

I will check your records any time during the weeks of this investigation. They must be kept up to date, and must be the original records.