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USING PROBLEM-BASED LEARNING AND HANDS-ON ACTIVITIES TO TEACH MEIOSIS AND HEREDITY IN A HIGH SCHOOL CLASSROOM

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USING PROBLEM-BASED LEARNING AND HANDS ON ACTIVITES TO TEACH MEIOSIS AND HEREDITY IN A HIGH SCHOOL BIOLOGY CLASSROOM

By

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ABSTRACT

USING PROBLEM BASED LEARNING AND HANDS ON ACTIVITIES TO TEACH MEIOSIS AND HEREDITY IN A HIGH SCHOOL BIOLOGY CLASSROOM

By

Tracie Dianne Krawczyk

While the students learn how to solve heredity problems quickly, they often do so in a way that is disconnected from meiosis, the process that creates variation. This unit was designed to address the issue of connection between meiosis and Punnett squares. I developed a thematic heredity unit that included problem-based learning activities that allowed students to work in small groups as well as activities that utilized models to teach difficult concepts. Students were assessed using pre- and post-tests. Students were also given pre- and post-surveys to measure their learning preferences before and after the unit as well as to allow them the opportunity to self evaluate their own learning. By the conclusion of the unit, students were able to solve difficult genetics problems with little guidance and were introduced to the connection between meiosis and heredity.

DEDICATION

Without the support of a special group of people, this paper would not be possible.

Thank you to my wonderful husband, Jason, and my sons, Jacob and Aidan. Any success I enjoy I owe to the three of you for your continuing love and encouragement. I promise we'll be able to go on vacations now!

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INTRODUCTION

Genetics, while fascinating, is a complex and abstract field of biology. Most aspects of this discipline are very challenging to ninth graders learning it for the first time. Meiosis and heredity rank in the top five of important concepts that are most difficult biological concepts for students to master (Finley, et al., 1982). Understanding the nuances of genetics requires both an application of prior knowledge and dedication. The focus of the study reported here was to teach how traits are passed on through generations by an integration of meiosis and heredity using hands-on activities and problem based learning opportunities. The students at the focus were ninth graders taking general biology.

While common knowledge to most now, the scientific basis of heredity was many years in development. As early as 4000 BC, people were using applied genetics to improve the quality of crops and domesticated animals. Ancient Hebrew laws indicate that this knowledge was applied to humans as well: baby boys born to women who bled excessively were exempted from circumcision. Boys of fathers who bled excessively were not; indicating that people of that time recognized what is now referred to as X-linked traits (Winchester, 1977).

An understanding of the mechanics of heredity came much later. Aristotle wrote that children could look more similar to a grandparent than a parent, an idea that disagreed with the Hippocratic view that traits were inherited from all parts of the body. Yet, he did not understand how this could happen (Whitehouse, 1965). William Harvey later proposed that, like birds, mammals must produce eggs as well in the body of the female. Anton van Leeuwenhoek described the presence of "animalcules" in human semen,

which were suggested by some to be parasites found in that particular sample. Leeuwenhoek disproved this idea by demonstrating that the small, wriggling organisms were found in the semen of every man in the study and several other types of animals as well (Winchester, 1977).

For many years after, there was much debate about the role that each parent plays in the development of an embryo. Jan Swammerdam hypothesized that each sperm contained a preformed "person" and that the woman's role in the development of the embryo was to provide a protection and nourishment in the womb. Pierre Louis Moreau de Maupertuis instead supported the role of epigenesis and, in a throwback to earlier ideas, suggested a blending of semen from each parent. Each parent's semen would have characteristics for each body part and, thus, the resulting offspring would have two "particles" for each part from each parent. Some particles could dominate the corresponding one. Therefore, the offspring may show a characteristic found only in one parent (Winchester, 1977). While certainly ahead of his time, it took the work of Gregor Mendel, an Austrian monk who studied pea plants at his monastery garden, for these ideas to become more accurate and concrete.

Mendel examined seven characteristics that affected seeds, pods, flowers, and stems of the plant, noting that characteristics came in two forms. Over the course of 8 years, he used some 28,000 pea plants in his breeding experiments and carefully recorded the results of his crosses, studying one pair of traits at a time. Mendel found that when he crossed plants with smooth seeds with plants with wrinkled seeds, all of the offspring had seeds that were smooth. It did not matter which plant provided the pollen, the results were always the same. He called the parent plants the P1 generation and the offspring the

F1 (first filial) generation. When F1 plants were self-fertilized, the offspring (F2) produced smooth and wrinkled seeds in a ratio of 3:1 of smooth to wrinkled. When he repeated this test for other traits, he found the same results: the trait which "disappeared" in the F1 generation "reappeared" in about 25% of the F2 generation. He referred to these reappearing traits as "recessive." Traits that appeared in each generation were referred to as "dominant" (Cummings, 2003).

Mendel realized that while the P1 and F1 smooth seed plants must have a different genetic makeup, observable traits appeared to be the same. Mendel described the physical appearance of the plant as its "phenotype," while the genetic makeup of the plant was its "genotype." Different genotypes could produce the same phenotype because each plant contained two genes for the same trait, one from each of its parents. In order for the recessive condition to reappear in the F2 generation, the F1 plants must have the genetic information for it, but not express it. It is only when two copies of the recessive trait are found together in the F2 generation that the phenotype is seen in the population (Cummings, 2003).

Mendel then sought to understand the transmission of these copies, now called alleles. Mendel reasoned that during gamete formation one allele of each gene is segregated into separate gametes. This became Mendel's First Law (Cummings, 2003). This explains why the F2 generation had a 3:1 ratio of smooth to wrinkled seeds. When the F1 generation self-pollinated, either a dominant or a recessive segregated into each gamete. If the offspring received two dominant alleles (now referred to as homozygous), the resulting phenotype would be smooth. If the offspring received one of each (now referred to as heterozygous), the resulting phenotype would be smooth, also. However, if

the offspring received two recessive alleles (homozygous), the resulting phenotype would be wrinkled.

Once he understood the mechanics of dominant and recessive, Mendel followed the crosses of two traits simultaneously. He found when he repeated his experiments, following the heredity of two traits, that the F2 generation demonstrated a 9:3:3:1 ratio for combinations of both traits. Using this information, Mendel developed his second law, the Law of Independent Assortment. Mendel proposed that the alleles for each gene separate into the gametes independently of all of the other alleles of the other genes (Cummings, 2003).

Molecular biology allows a more complete explanation of how these laws work. Meiosis is the division of nuclear material into gametes. While meiosis has many of the same characteristics of mitosis (somatic cell division) there are two sets of division instead of one in order to reduce the number of chromosomes by half. Each cell begins with a full compliment of chromosomes (2n). While mitosis produces genetically identical daughter cells (2n), meiosis produces genetically different daughter cells that typically have different combinations of alleles (n). During the first stage of meiosis I, chromosomes coil and become identifiable within the cell. Every chromosome then pair with its homologous chromosome, a structure that has the same genes on it but not necessarily the same alleles. Each chromosome has duplicated to form two identical sister chromatids attached together by one centromere. All four sister chromatids then line up across the equator of the cell. During the first meiotic division, one of each homologous pair separates into two different cells. The division of these homologous pairs is random, leading to different combinations of chromosomes and, thus, alleles,

explaining Mendel's Law of Independent Assortment. During the second meiotic division, sister chromatids separate forming a total of four gamete cells, each of which has one allele for each gene. This division explains Mendel's Law of Segregation (Lewis and John, 1964). When the gametes fuse together, the offspring will have the full complement of chromosomes in a combination that will most likely not be like either parent.

An additional source of genetic variability is produced during meiosis I after homologous chromosomes line up along the equator of the cell. Sometimes pieces of sister chromatids can be switched between the homologous chromosomes. This allows for new combinations of alleles to be possible.

Predicting the outcome of genetic crosses has much to do with predicting the probability that a gamete will have a particular set of alleles and match up with a gamete that has another particular set of alleles. This is usually represented as Punnett squares. Understanding meiosis as it relates to heredity is important in understanding the fundamentals of each and their importance. However, this can be difficult for students. Often these concepts are presented in a disconnected way; meiosis is taught along with mitosis and heredity is taught later on. This may lead to results like those found by Stewart, et al. (1990): When students were asked to explain how they arrived at the solution for genetics problems, their answers were only infrequently connected with Mendel's Laws or an accurate understanding of the process of meiosis. Many could not explain why their Punnett squares were set up as they were. Indeed, many students do not reach a deeper understanding of the concept and rely purely on algorithm to solve the problem. (Stewart, 1982) This is not a strategy that teachers want their students to use.

Experience in my own classroom has led me to this conclusion as well. Many students found simple Mendelian genetics and monohybrid (1 trait) cross problems "easy" because they were only expected to use an algorithm to solve the problems in the past. However, there was a real lack of connection to deeper understanding of complex biological concepts. As a result, many of my students have had difficulty in the past solving dihybrid (two trait) cross problems. Stewart (1982) found this to be true as well. Because students relied on algebraic functions to solve dihybrid crosses, they were often confused when asked how these solutions related to gametes. Students could not explain why incorrect combinations of alleles were incorrect. They could only identify correct solutions. He also found that students had trouble relating associated concepts together, such as gene-chromosome and allele-trait.

Instruction using meiosis reasoning problems has been shown to increase student understanding and more accurately assess conceptual models they develop (Kindfield, 1994). Problem-based learning models, particularly ones that utilize the Piagetian model of development, allow students to master concepts in a step wise fashion that encourages ownership of learning as well as progress to increasingly more difficult problems. (Walker, et al., 1980) Students use inductive methods to approach and solve these problems, leading to a richer understanding of the material, not simply rote memorization. Each new problem requires the student to revisit previously developed concepts, relate the new problem to the concept, and then work through contradictions between the new set of data and the previous conceptual model. This is accomplished through deductive reasoning. Watson's group found that students who learned genetics using this method scored 6-10 points higher than a control group on a summative

assessment (Watson, 1991). The control group learned the same information using traditional lecture and laboratory methods. Watson concluded, "If the objective of instruction is to produce students capable of critically analyzing complex data, then the instructional strategy should focus on the form of systematic sequential thought appropriate to the analytical procedures applied in the discipline." Such a method of instruction is problem-based learning.

Problem-based learning involves presenting open-ended problems to small groups of students. Teachers act as facilitators for these groups as they develop knowledge in a particular content area (Goodenough & Cashion, 2006). A key feature of this method is the collaboration, or cooperative learning, that takes place within the group (Evenson & Hmelo, 2000). This method of instruction was first described by Howard Barrows (as cited in Nendaz & Tekian, 1999), as early as 1986, and applied to medical school curriculum. Barrows described four main objectives to problem-based learning: "(a) structuring knowledge for better recall and application in clinical contexts; (b) developing an effective clinical reasoning process; (c) developing self-directed learning; and (d) increasing motivation for learning" (Nendez & Tekian, 1999). Since then, it has been applied to other disciplines. This instructional method takes on a cooperative learning structure, defined as a "structured form of group work where students pursue common goals while being assessed individually" (Prince, 2004).

By taking on this problem-based learning approach and utilizing cooperative learning environments, student enjoyment as well as success can be raised. Research on problem based learning as a learning strategy has found that the 12 proven benefits include not only higher achievement, but greater use of higher level reasoning strategies, positive

attitudes toward the subject matter, positive attitudes toward teachers, and greater on-task behavior (Lord 1994). While this method of instruction has been used for many years in other subject matters like medicine, it is equally effective in the sciences (Watson, 1991). Students of teachers involved in Lord's study reported that the students enjoyed learning from each other and looked forward to attending class. Research also supports the community learning concept increases the depth of knowledge and understanding as students discuss answers and learn from each other (Sharan and Sharan, 1990).

Other active learning strategies were also employed including the use of models and "think-pair-share activities." "Think-pair-share" is a method of cooperative learning that allows students to process content information from a formal learning setting such as a lecture or class discussion. Using this method, students first think and develop a written response independently to a question posed to the class. Next, students "pair" up to discuss their answers together. Finally, the groups share their answers with other groups during a class discussion (D. Walker, 1998).

In this study, problem-based learning and active learning strategies, including those mentioned above, were employed to teach a unit on genetics and heredity to ninth grade biology students at Almont High School. Item analysis of pre- and post-test questions was used to determine the effectiveness of utilizing these learning strategies. Student self-assessment was also considered using data collected from pre and post-surveys administered to participants.

Almont Community School district is located in the village of Almont, approximately 32 miles north of Detroit in Lapeer County. Almont has limited racial and ethnic diversity, with approximately 96% of citizens being Caucasian as of the 2000 census.

Approximately 3% of the population is Hispanic or Latino, with a number of citizens who are seasonal workers. The population is a mix of upper lower and lower middle class blue-collar workers with a smaller population of white collar workers. Companies that are tied to the automotive industry, either as Tier II suppliers or as automotive assembly plants, employ most workers in Lapeer County. In Almont, the largest employer is the school district itself. It is a small school district of approximately 1800 students grades K-12. The district has four buildings: a primary (K-2), an elementary (3-5), a middle school (6-8), and high school (9-12). As recently as 1987, the entire school district was contained in one building. During the nineties, the area experienced a large population growth leading to the building of the primary and middle schools. The district also provides services for children from the surrounding Almont Township and accepts students from bordering districts as part of a "schools of choice" program. In addition, Almont High School also hosts the Cognitively Impaired and Emotionally Impaired special education programs for Lapeer County. Almont High School has a student population of 601 students. The majority of students take a basic college prep curriculum during the ninth grade. The majority of Almont graduates (60%) will enroll in a college, university, or trade school. Others enlist in the armed forces or seek employment. The dropout rate is approximately 4-6%. The daily attendance rate is 96%.

IMPLEMENTATION

I currently teach Biology to nearly every ninth grader at the high school. Since I began teaching at Almont eight years ago, I have worked each year to modify, add, and redesign curriculum for the biology and life science programs. Recently, the eighth grade life science and ninth grade biology classes have exchanged some of the curricula. Last year, ninth grade biology included the genetics and heredity unit for the first time. I chose heredity and meiosis as my focus of research in order to have the opportunity to concentrate on the unit and sequence curriculum that would be hands-on and relevant for my students. The students in the study were from two of the five classes of Biology taught this year that had the highest rates of voluntary participation. Students in these two classes represent a broad range of past scholarship and, therefore, seemed to best represent the entire grade. Eleven of 28 students volunteered to participate in the study from fourth hour and 16 of 21 students volunteered from fifth hour. All students who volunteered to be part of the study read and signed a consent form (Appendix A) to allow their data to be analyzed and reported. Each student also had a parent or guardian grant permission for use of the data as well.

The unit's major theme was to explain how variation might occur between two closely related individuals using knowledge of genetics and meiosis. In order to accomplish this goal, the unit was broken up into sections. Each section focused on a particular topic with the goal of building knowledge to solve open-ended problems. PowerPoint presentations were utilized for the directed instruction portions of each section, and mainly included introductions and summative activities. Students were largely responsible for the acquisition of knowledge through problem based scenarios and

short labs or group activities. In order to achieve the goal of learning both heredity and meiosis, each section had a particular goal and correlating activities associated with it (Table 1).

Table One: Scope and Sequence of Heredity Unit

Section/Topic	Objectives	Activities
1. Introduction	Review of connections between traits and genes	Cat hair lab; Think-Pair-Share problem
2. Terminology	Students will explain the following terms: dominant, recessive, homozygous, heterozygous, genotype, phenotype; Students will recognize homologous chromosomes	Cat hair lab 2; Bert and Ernie Go the Cat Breeder
3 &4. Punnett Squares	Students will be able to predict the outcome of a monohybrid cross	Think-Pair-Share Problem; Group Punnett Square Problems; Charlie the Cat PBL
5. Meiosis	Students will describe the major events of Meiosis I and II; Students will explain the laws of segregation and independent assortment and how they lead to variation in gametes	Sockosomes; Reebop building; Humans as Chromosomes; Human Karyotyping On-Line
6 & 7. Inheritance of co-dominant and sex linked traits	Students will determine the probabilities of traits which are sex-linked or co-dominant	Spot the Cat PBL; A Tail of Two Kitties PBL

The heredity and meiosis unit was developed at Michigan State University during the summer research experience. It was planned to last six weeks of course time. All activities, except the on-line karyotyping activity, were new to the biology course and were compiled or developed over the course of the summer at Michigan State University.

Movement within the district science curriculum warranted the addition of this unit in the biology course, and the unit was written to fulfill this requirement.

A pretest on heredity and meiosis (Appendix B) was administered that included both open-ended and multiple choice questions to gauge students' prior knowledge. Due to the fact that open-ended questions elicit a variety of responses, answers to most of these questions were scored on a scale of 0-3 points. A few questions were scored on a scale of 0-2. In either case, zero points were awarded for no response or for responses that were completely wrong and the maximum points represented a superior answer. Other answers were rated based on correctness. Each open-ended question had its own scoring rubric (Appendix B). A sample rubric is included here to provide an example of how points were awarded on various questions. Questions 2-5 ask students to explain the outcomes of a cross between two human parents. The father has brown eyes (B) and straight hair (c). The mother has blue eyes (b) and curly hair (C). Scoring for question 2 is described below (Table 2).

Table 2: Pretest rubric sample

Question 2: Explain why you have eyes like your father and hair like your mother.	
Points awarded	Responses
3	Describe dominant and recessive alleles to explain how inheritance happened
2	Describe dominant or recessive alleles to explain how inheritance happened.
1	Parents passed on different genes (for different traits) OR mentioned "strength" of gene
0	Completely incorrect/no response

Multiple-choice questions were scored one point for correct answers and zero points for all other answers. The pretest had 23 multiple-choice questions (Appendix B). Some

of these questions assessed prior knowledge of vocabulary while others assessed student knowledge of meiosis and Punnett square outcomes. A complete answer key can be found in Appendix B.

A unit pre-survey (Appendix B) on student preferences for different instructional methods was also given to determine student preconceptions and perceptions of lecture, lab, modeling, and problem based learning activities. This information was used to determine attitudinal changes and preferences after completing the unit and post survey. Students were given a choice of numbered responses to use for each question ranging from 1=strongly disagree to 5=strongly agree.

The unit itself was broken up into seven sections (Table 1). While the first few sections were more guided, the activities became more student-centered as the unit progressed.

Section One:

This section, entitled "Lucky Stripes" (Appendix C), introduced students to the cat-breeding theme upon which each of the problem based learning activities would be based. Students were given background information and photos of a striped cat, a black cat, and their litter of two striped kittens and one solid kitten. Students were then charged with the task of figuring out why the kittens of these two cats looked like either parent instead of a mixture. They first took part in a "think-pair-share" activity, allowing them time to think first individually, and then share their ideas with a partner, and finally participate in a class discussion of the question. In order to get a more complete idea of the differences between the cats, students examined, using hand lenses, the striped hairs of one cat and

the solid hairs of another and made sketches and written observations on the handout for the lesson.

After discovering that the individual hairs were colored differently (striped cats have striped hair, not patches of alternating color), students related the information to what they had already learned about basic protein synthesis from a previous unit. They were then given a reading assignment from their text book (Biology: The Dynamics of Life, Glencoe/McGraw Hill) about Gregor Mendel for homework. This reading assignment was to give them some background information in formulating a hypothesis about the day's problem and to give them a foundation for the next unit on vocabulary.

Section Two:

The second section, "Graycie," focused on vocabulary acquisition, an often difficult part of learning genetics due to the large volume of unfamiliar words that sound very similar. Students examined the hairs of "Graycie," a grey striped cat, and "Fizzy," a black striped cat, with a hand lens. Drawing from the previous day's lesson on stripes and no stripes, students were asked to conclude why one cat was lighter than the other. In order to learn why, they paired off to read through "Bert and Ernie Go to the Cattery." This script, written by classmate Kelly Joos and me introduces the concepts of dominant and recessive, homozygous and heterozygous, and genotype and phenotype. Students used the Bert and Ernie dialogue to answer questions about the key terms and then join in a class discussion about them. Using what they learned from the script, students then applied the new terms to explain why Fizzy and Graycie different. They also applied this knowledge to the section one problem to build an answer about why Fizzy and Baby's

kittens look as they do. A summative assignment (Appendix C) was given for students to complete individually for homework in order to review the terms learned.

Section Three:

The third section, "Learning Punnett Squares," introduced the concept of predicting the outcomes of a monohybrid cross. The instruction began by showing a Punnett square as chromosomes so that students could relate them to chromosomes and gamete division. Referring back to the two previous cat problems, a "think-pair-share" activity was conducted to develop Punnett squares for heredity problems studied in sections one and two. Students were given practice problems as homework. After students returned very uncertain about completing the problems on their own, two days of class were spent practicing problems: one day going over the homework problems and a second day working on new problems during class where they had access to assistance.

Section Four:

The first student-centered problem-based activity took place during this section. The problem, titled "Charlie the Cat," introduced a champion black cat whose lineage was being challenged by a competitor who did not believe that two all white cats could produce a black cat. Students were given supplementary materials (Cat Coat Color Genetics – Appendix C) to work through the problem and produce a Punnett square to either prove or disprove the competitor's claim. Using their understanding of simple dominant and recessive, groups of two worked through the problem.

Section Five:

Section five introduced the concept of meiosis and the resulting genetic variation. The goal was to develop a deeper understanding of heredity and why Punnett squares allow

one to make predictions about the outcome of breeding two organisms. Students used models, "sockosomes" (Appendix C), for a visual and tactile way learn the major events and outcomes of meiosis I and II. Four students played the role of "giant sockosomes" while the remaining students worked in pairs with their models to follow along with the PowerPoint lesson.

The second activity in the section was small group centered. Four students worked together based on the handout "Meiosis and Fertilization" (Appendix C). Using the sockosomes, the small groups discussed the first and second division of meiosis. A group assessment was administered to determine whether or not group members completely understood what they had read.

The third activity, "The Reebop Family" (Appendix C) brought together the relationship between gamete formation and Punnett squares. Students were given envelopes with chromosomes for each Reebop parent, marshmallow creatures with several phenotypes for body features such as eyes and antennae. Students randomly choose chromosomes from each parent pair to form a Reebop offspring genome. After completing the genotype and phenotype of the offspring on paper, various materials were used to construct the offspring and they were placed into the Reebop "nursery" for comparison. Because each set of parents had the same genotype, the offspring could be compared as possible offspring of the same cross.

To reinforce variation of gametes, students participated in the final activity of the section, "Human Chromosomes." Each student played the role of a chromosome with two gene loci. The human chromosomes lined up with their homologous pairs and completed meiosis I and II by moving to different sections of the room. The genotypes

of the gametes that resulted were recorded on the board for each round to compare. Once this had been practiced a few times, the concept of crossing over was introduced by showing the students how to switch the labels for one of the genes between two non-sister chromatids. After Meiosis I and II, the resulting gametes were recorded on the board to compare with the first rounds. After practicing a few more times, three additional rounds were completed and a random gamete from each round was chosen to fertilize a gamete I selected. Students derived the genotype and phenotype for each of these offspring and drew a picture of each. Finally, they completed challenge questions to help them summarize what they had learned from the activity.

Sections 6 & 7:

Sections six and seven consisted of problem based activities that were student led. Section six, "Spot the Cat" (Appendix C), was a problem that introduced the concept of co-dominance. Using the resource packet and the concepts learned in the unit, students determined how it was possible that a spotted cat could have a solid sibling. In the seventh section, students completed a problem related to sex linked traits. Students determined why a tortoise shell cat (a "tortie") had a litter with such a variety of phenotypes. After these problems, students were given an individual problem to solve based upon one of the two completed as a team.

At the conclusion of the unit, the students were administered a two part post-test (Appendix B). The first part was open ended and assessed knowledge of vocabulary, Punnett squares, and outcomes of Meiosis I and II. This part was a graded assessment for the students. However, scores from this assessment were not included in data collection for the study. The second part was an assessment comprised of the same questions as the

pre-test, and was scored using the same rubric (Appendix B). This portion was not assessed for a grade and was used for data collection for this study.

Students were also given a post-survey (Appendix B). First, these questions were the same as those on the pre-Survey and meant for comparison to measure changes in attitudes and preferences for different instructional techniques used in the unit. Second, students were asked about specific activities from the unit to gauge student opinion on the usefulness of each. Finally, students completed a self-assessment of their learning based upon the goals of the unit (Table 1) using the remainder of the questions in the post-survey.

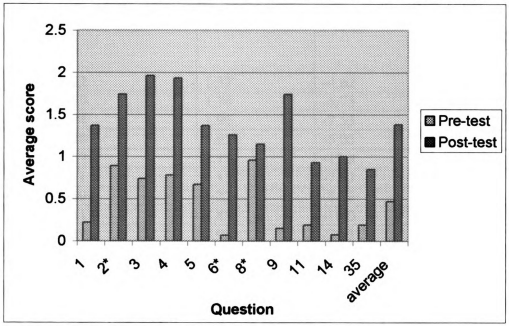
As with the pre unit survey, student responses to each statement on the post unit survey were measured from 1-5 and used the same titles as those of the pre-survey (Appendix B). However, some of the questions were brand new, while others were different from the pretest but correlated with a pretest question. These questions were more specific with regard to an activity on the post-test than on the pretest.

RESULTS

Several assessment tools were used to determine the effectiveness of the new heredity and meiosis unit developed for the biology course at Almont High School. The pre- and post-tests, and pre- and post-surveys were used to make this determination along with results of various embedded assessments (summative activities and group work).

The pre-test was administered to determine student prior knowledge and to measure growth in knowledge as a result of the unit. The test consisted of both open ended and multiple-choice questions. Generally, answers to open ended questions were assigned points according to a rubric (Appendix B) on a three-point scale, though a few questions were graded on a two-point scale. By providing more information, students were awarded more points. Students with completely wrong answers or no response to the question were awarded zero points for the test item. Scores for the open-ended questions (Figure 1) were low, as expected. Average scores for each of the problems were all below 1 point. Objective questions on the test account for the gaps in the numbering on the figure.

Figure One: Comparison of Pre and Post-Test Scores On Open-ended Questions



*denotes question scored out of possible 2 points instead of 3

Several questions had results that were quite low for the simple reason that the question was left unanswered by many or most students. Other questions had quite high averages (number eight), which can be attributed to knowledge gained from the prior unit over protein synthesis. Scores overall improved on each open-ended question on the post-test taken at the conclusion of the unit (Figure 1).

In general, improvement occurred for each question, and the average score for test increased. Most of the results were statistically significant based on a paired t-test analysis. Table 3 contains the results of the statistical analysis of the open-ended questions.

Table 3: Results of Statistical Analysis of Open-ended Questions from Pre/Post-test (N=27)

Question	Pre-test mean	Post-test mean	t-value	Statistically significant at p=0.05
1	0.22	1.37	-4.62	Yes
2*	0.89	1.74	-5.75	Yes
3	0.74	1.96	-7.53	Yes
4	0.78	1.93	-6.05	Yes
5	0.67	2.19	-12.3	Yes
6*	0.11	1.15	-7.63	Yes
8*	0.89	1.22	-1.73	No
9	0.11	1.85	-10.0	Yes
11	0.19	0.96	-3.61	Yes
14	7.41E-02	1.00	-4.22	Yes
35	0.19	0.93	-3.31	Yes

The first question dealt with connecting three key terms together: gene, allele, and chromosome. The average pre-test score, 0.22 out of 3, resulted from most students not being able to connect even two of the terms together. In fact, the students who scored any points on this problem did so by simply describing one of the terms without connecting it to another. On the post-test (Table 3), this score improved to 1.37 out of a possible 3. More students were able to correctly connect at least two of the terms together. Very few were able to connect all three without being too general to be able to assess whether a deeper understanding had been reached. These concepts were first introduced in the first section, the Lucky Stripes PBL (Appendix C), and were reinforced throughout the unit. The improvement made is considered statistically significant at the 95% confidence level with $P<0.05$ (Table 3).

Problems 2 – 6 (Appendix B) were based around a human heredity situation. Out of a possible two points, the average pre-test score for question 2 was 0.89 points. Student

responses earning points often included information about inheriting genes from certain parents, however few of these mentioned inheriting genes from both parents for each gene. This type of response was anticipated due to MCCF benchmarks for heredity that expect students in middle school to learn that traits are inherited from parents, and that parents have the traits themselves. Students who mentioned inheriting genes from both parents included in their responses that the "strength" of the genes makes a difference. They thought that the genes of one parent might have more strength than that of another parent. However, they did not mention whether this was due to the actual gene itself or to the parent the gene belonged to. During class discussions, several students mentioned that they thought the sex of the parent made a difference; either that the same sex parent largely contributed to the gene or that certain genes were stronger for certain parents in general, for instance, eye color largely being controlled by one gender of parent in every case. This score improved on the post-test. The class average for this question improved to 1.74 out of 2 (Table 3).

Given the results of the paired t-test, the null hypothesis was rejected, indicating that their increase in score was due to the instruction received during the unit. Students mentioned the terms "dominant" and/or "recessive" in their answers, demonstrating their use of new vocabulary and its applications to new situations.

Questions 3 and 4 (Appendix B) dealt mostly with differences and similarities between siblings and offspring based upon the laws of independent assortment and segregation, though the problems do not specifically mention these laws by name. Students averaged 0.74 points out of three on question three and an average of 0.78 for question four on the pre-test (Table 3). Most students reported that it depended upon

which genes each parent gave, earning one out of three points, but none of the students mentioned dominant or recessive genes being the reason why for either question. At the conclusion of the unit, students did mention the terms dominant and/or recessive much more frequently in both answers, resulting in an increase in the average score for the two questions (1.96 and 1.93, respectively). In both cases, the null hypothesis was rejected and the results of the t-test are statistically significant. However, students generally did not use information about the law of independent assortment in their answers, as I expected. This result was consistent with the results of the Human Chromosome Activity analysis. The final question of this assessment asked students whether it is possible for two siblings with the same parents to look differently (this is the same as question four on the pre and post test). Students generally did not use information about the law of independent assortment in their answers, even though the activity as well as the question preceding it was about this law. Most students in this case also relied more on their understanding of Punnett squares to answer the question or were vague in their response ("It depends on what each parent gives.") Perhaps a better-structured question is necessary in the future to direct student thinking, allowing for a better analysis of the connection in students' minds between these ideas.

Question five (Appendix B) asked if it were possible to have children with both the same eye and hair color as one of the parents. Students averaged 0.67 points out of a possible three, with most mentioning, again, that it depended upon which of the alleles the parent of interest gave to the child. On the post-test, the class average for this question was 2.19 of a possible three points (Table 3). The t-test for this question indicates that the null hypothesis is rejected and that the results are statistically

significant. While most students were able to explain that dominant and recessive traits, 6 out of 27 (22%) mentioned that the child's traits might also depend upon the other parent due to recessive traits of the first. This answer earned 3 out of 3 points and represented a superior answer. Like the last two questions, this question required students to combine their knowledge of vocabulary with their understanding of Punnett squares and probability. However, they also needed to apply their knowledge of the law of independent assortment, at least in a broad sense, to understand that the gametes used to create one sibling may not be the same for the other.

Question six (Appendix B) asked students to connect the process of meiosis with Punnett squares. As expected, the score for this question was low on the pre-test, with 0.07 out of 2 points being the average. This was mostly due to lack of familiarity with the concepts or vocabulary used in the question. Students who did earn points on this question mentioned the word "heredity", but did not offer any supporting evidence of their understanding. One of these two students had transferred from another school district where Punnett squares were covered in middle school and was able to offer that it had "something to do with those boxes." But this student could not remember what the boxes were for or why one set them up as they are. On the post-test, many more students mentioned the word "heredity" (13 out of 27 students). Nine more students were able to explain either meiosis or Punnett squares. Only one student of 27 could explain how the two were connected. Perhaps a rewording of the question would have yielded better results. Student learning did take place, however. The results of the t-test indicate that the null hypothesis was rejected and that the results were statistically significant (Table 3).

Question eight (Appendix B) asked students to explain what a chromosome was. Chromosomes had been covered in a previous unit and many students could offer that chromosomes were pieces of DNA. This answer earned 1 out of a possible 2 points. The pre-test class average for this question was 0.96 out of 2, demonstrating that the majority of the students came with some of this background knowledge. On the post-test, the average increased to 1.15 points, showing that some students also knew that chromosomes had genes on them. However, the improvement on this question was not statistically significant (Table 3). The null hypothesis is accepted in this case because the p-value is greater than 0.05. Perhaps more students were able to only give the information learned previously than those who were able to expand on their prior knowledge. Having learned the information once, it became the answer they knew and additional information was not remembered.

Question nine asked about the purpose of meiosis. This concept was brand new for these students, and the pre-test score was expected to be low. The average score was 0.19 out of a possible three, with many students mentioning that it had something to do with chromosomes. This answer could have been influenced by the previous question, because this score, while low, was still much higher than I expected. The post-test average was 1.74 out of three (Table 3). The results of the t-test indicate that the null hypothesis was rejected because the p value was well below the 0.05 at the 95% confidence level. Answers earning two points on the post-test included "meiosis is the process by which gametes are produced." About half of the students assessed (13 out of 27) earned two points. Students who mentioned that meiosis also had to do with the reduction of chromosome number earned more points, as did those who mentioned the

"shuffling" of chromosomes. Five of 27 students earned three points for their answer. Again, a more directed question may have resulted in more specific answers. Information for this question was presented during the Reebop, Sockosomes, and Humans as Chromosomes activities (Appendix C).

Each student looked at a picture of a human karyotype in question 11 (Appendix B) to determine which chromosomes came from the mother. The goal of this question was to find out if the student knew about homologous pairs, the source of each chromosome of a pair, and whether or not the student knew the difference between sex chromosomes. The average score on the pre test was 0.19 points. Most of the students, 14 out of 27, did not even answer the question. This score improved to 0.96 out of a possible 3 (Table 3). Statistically speaking, the t-test resulted in the null hypothesis being rejected. Many students were able to at least identify the sex chromosomes or circle one chromosome from most of the pairs. While the statistical analysis indicated that the improvement on the question was significant (Table 3), anecdotally, the question did not allow for good results. Even after the unit was taught, many students still had difficulty answering this question. Although the number of students who did not answer the question dropped to three, nine out of the remaining 24 students who did answer incorrectly by circling whole pairs of chromosomes. Other students (10 of 27) either circled only one sex chromosome, only one homologous chromosome from each autosomal pair, or some combination of both.

Number fourteen (Appendix B) is related to question eleven, asking students to explain whether or not two chromosomes were homologous and why. The two chromosomes both featured hair color loci, yet not for the same hair color. Students who

correctly answered this question indicated that they were homologous because they had the same gene (for hair color) in the same location. On the pre-test, the average score for this answer was 0.30 out of three points. The post-test average was 1.00 out of a possible three points (Table 3). The number of students who left the answer blank decreased to 3 out of 27 students, and 15 out of 27 students were at least able to explain that they both had a hair color gene on the chromosome, though only 7 mentioned that it was in the same location. Results of the paired t-test do not support the null hypothesis.

Question 35 (Appendix B) asked students to explain why only the boys in a family were affected by a particular disorder. On the pretest, the average score was 0.19 out of 3. The majority of students, 21 out of 27, left the question completely blank. On the post test, this score improved to 0.93 out of 3. (Table 3). The null hypothesis is rejected according to the results of the t-test. Six of 27 students left the question blank again, but 12 of the 27 students mentioned gender as a factor in their answer. Four of the 27 were able to connect the information from the Problem Based Learning activity on sex-linked traits (A Tail of Two Kitties PBL) to the problem and explained that the key to the answer was the X chromosome.

The remaining questions on the assessments were objective in nature. Several were arranged as clusters, and so will be discussed this way. Questions 12 through 18 (Appendix B) concentrated on the details of meiosis. Students scored one point for each correct answer, and zero points for wrong or missing answers. The results of these answers are represented in Figure 2 and in Table 4.

Figure 2: Students Correctly Answering Questions in Meiosis Cluster (N=27)

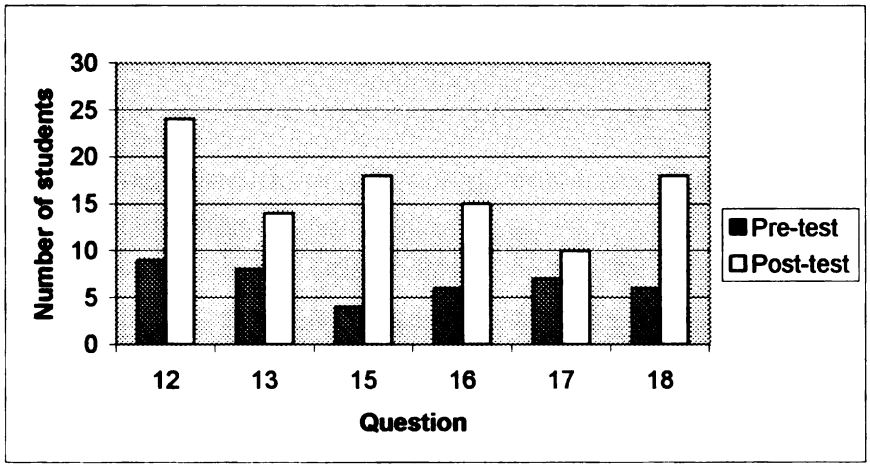


Table 4: Results of Objective Questions, Meiosis Cluster

Question	Pre-test Mean	Post-test Mean	t-value	Statistically significant?
12	0.33	0.85	-4.19	Yes
13	0.30	0.52	-1.65	No
15	0.15	0.67	-4.19	Yes
16	0.22	0.52	-2.13	Yes
17	0.26	0.37	-0.90	No
18	0.26	0.70	-4.00	Yes

Question twelve (Appendix B) dealt with vocabulary, specifically the term "haploid." Students had to identify the correct description of a haploid cell. The results of a paired t-test reject the null hypothesis (Table 4).

Differences between the pre and post-test for number 13 (Appendix B) were not significant, however. The question asked students to apply the definition of diploid to the combination of gametes. The results of the t-test show p=0.110, far above the p value of 0.05 needed to meet the 95% confidence interval. This concept would have been covered during the Sockosomes, Reebop, and to a smaller degree, Humans as Chromosomes activities.

Question 15 (Appendix B) asked about the products of meiosis. This was covered primarily during the Sockosomes and Humans as Chromosomes activities. This objective was met. Four students answered correctly on the pre-test, and 18 answered correctly on the post-test. The result of the t-test indicated this difference to be statistically significant.

Question 16 (Appendix B) assessed student understanding of recombination. Students had to pick out "mitotic division" as a process that would not result in genetic recombination. The increase in correct responses between the pre- and post-test were found to be statistically significant ($p=0.04$) (Table 4). However, when asked to explain the law of segregation in question 17, the differences in responses were not statistically significant to show a gain ($p=0.38$).

Students did seem to learn the basic steps of meiosis. Question 18 (Appendix B) asked students to determine the outcome of the first meiotic division. Where six students answered correctly on the pre-test, 18 answered correctly on the post-test. The paired t-test for student data on this question shows that this increase is statistically significant (Table 4).

The next cluster of questions dealt with vocabulary used in heredity and genetics: genotype, phenotype, dominant, recessive, homozygous, and heterozygous. Results of assessment from this cluster are found in Figure 3 and Table 5.

Figure 3: Correct Student Reponses to Questions from Heredity Vocabulary Cluster (N=27)

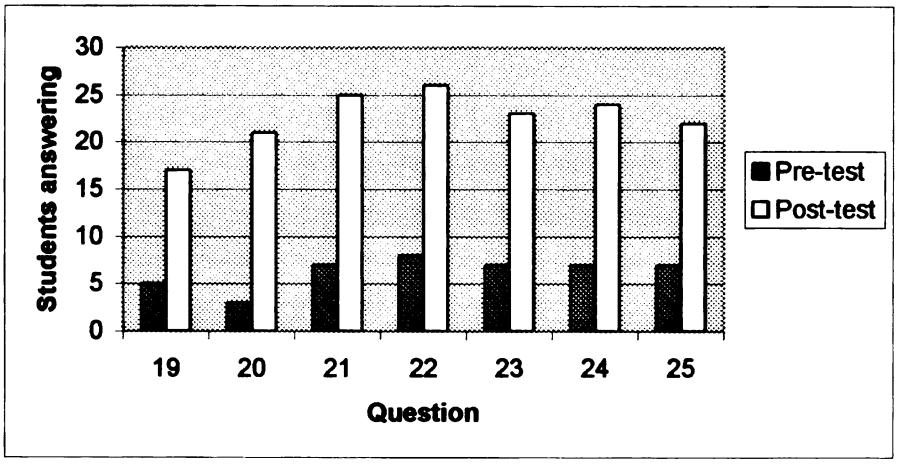


Table 5: Results of Objective Questions, Heredity Vocabulary Cluster

Question	Pre-test Mean	Post-test Mean	t-value	Statistically significant?
19	0.19	0.63	-4.00	Yes
20	0.15	0.78	-5.20	Yes
21	0.22	0.89	-6.24	Yes
22	0.26	0.93	-6.24	Yes
23	0.26	0.85	-6.15	Yes
24	0.30	0.89	-5.38	Yes
25	0.26	0.82	-5.00	Yes

Results from this section indicate that the differences between the pre and post-test for the heredity vocabulary section were statistically significant, with p=0.000 for each one. These terms were introduced in the "Bert and Ernie" activity and reinforced through each PBL activity.

Heredity problems that were not simple dominant and recessive, such as co-dominance, were the focus of the last cluster of questions (questions 26, 28, 29, 32, 33, and 34) on the formal assessment (Appendix B). Results of this section are shown in Figure 4 and in Table 6.

Figure 4: Correct Student Responses to Punnett Square Cluster (N=27)

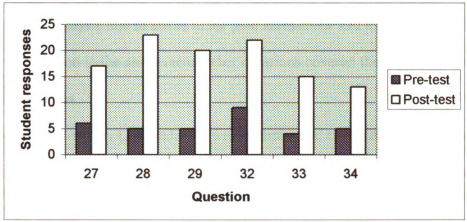


Table 6: Results of Objective Questions, Punnett Square Cluster

Question	Pre-test Mean	Post-test Mean	t-value	Statistically significant?
27	0.22	0.70	-4.31	Yes
28	0.15	0.82	-7.21	Yes
29	0.19	0.74	-5.00	Yes
32	0.41	0.82	-3.70	Yes
33	0.15	0.59	-3.61	Yes
34	0.22	0.52	-2.53	Yes

Results of paired t-tests for each of these questions indicate that the results were statistically significant. These questions required that students be able to complete a Punnett square of a monohybrid cross, and then calculate genotypic and phenotypic ratios. Students practiced these during each of the PBL activities as well as in practice problems assigned during the unit. Through this assessment, they demonstrated their proficiency at monohybrid crosses. The two questions with which they had a little trouble dealt with co-dominance and recognizing the phenotype related to co-dominance. While the notation used in the assessment was slightly different, about half of the students were still able to recognize and distinguish the proper notation given four choices.

Four questions (7, 26, 36, 31) (Appendix B) on the pre- and post-assessment were not used in the data analysis due to errors in the post assessment and irrelevance. However, because of repetition in the assessment, other questions covered the same topics and were used in this analysis.

A pre- and post-survey (Appendix B) was administered to students to measure their changes in attitude regarding teaching methods before and after the unit, as well as to allow them an opportunity to self-assess their learning.

Students reported that they were better able to predict the outcome of a breeding experiment by the end of the unit (Figure 5). They also reported that they were better able to explain how parents pass on their traits to their offspring (Figure 6).

Figure 5: "I am able to correctly predict the outcome of a breeding experiment."

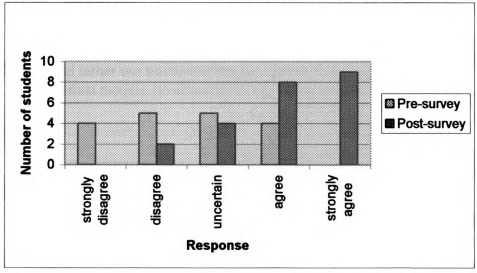
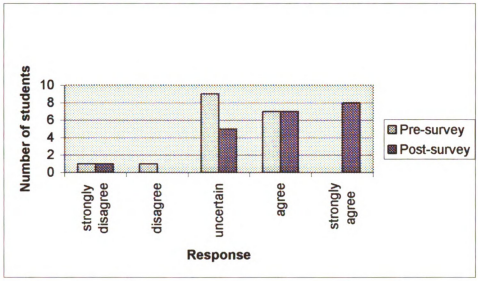
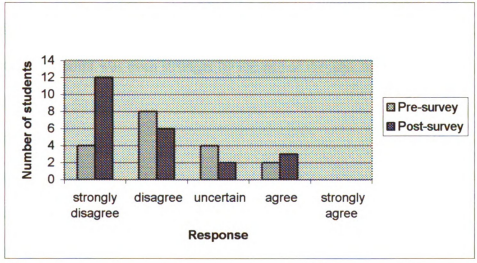


Figure 6: "I am able to explain how parents pass on their traits to their offspring."



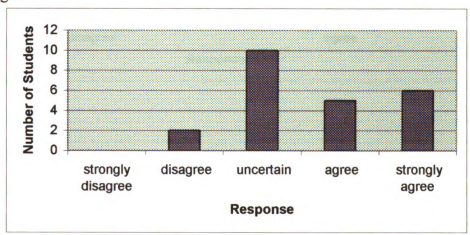
Students also felt that the methods of instruction used were preferable to more traditional methods of deliver, namely lecture and book work (Figure 7). Results of the post-survey indicate that this view was even stronger after the unit.

Figure 7: "I would rather use traditional lecture and book work activities to learn difficult concepts than models, problem-based learning, and other group activities.



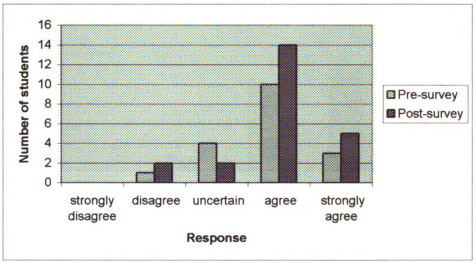
By examining student responses to questions, opinions about specific teaching methods and their effectiveness were also learned. The activity dealing with vocabulary acquisition was favorably viewed (Figure 8).

Figure 8: "Participating in 'Bert and Ernie Go to the Cat Breeder' helped me to understand the terms phenotype, genotype, dominant, recessive, heterozygous, and homozygous



Students also reported that the use of models was helpful in learning the difficult concepts covered in the unit. While students had expressed this view initially in the pre-survey, this viewpoint was even stronger by the end of the unit, as reported in the post-survey (Figure 9).

Figure 9: "Using models helps me to explain material covered in class better."



Examples of modeling activities included the Sockosome, Reebop, and Humans as Chromosomes activities (Appendix C). Students reported on the post-survey (Appendix B) that the Reebop marshmallow activity was enjoyable (Figure 10), however, they also reported that they were uncertain about the concepts the activity was based on (Figure 11). The sockosome modeling activity also left students uncertain about the concepts involved (Figure 12).

Figure 10: "The Reebop activity (marshmallow creatures) was enjoyable."

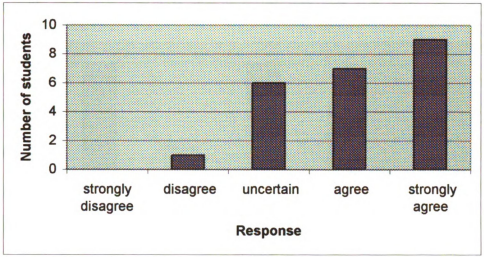


Figure 11: "After completing the Reebop activity, I was able to understand how the law of independent assortment can lead to differences in the population."

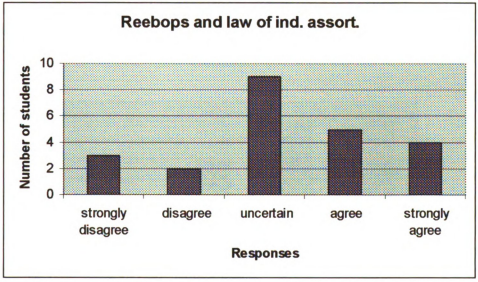
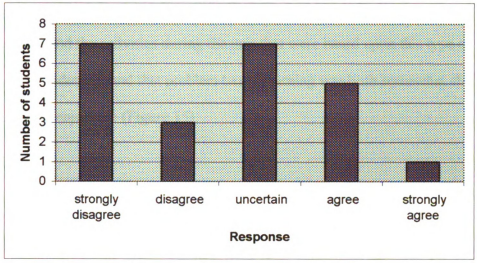
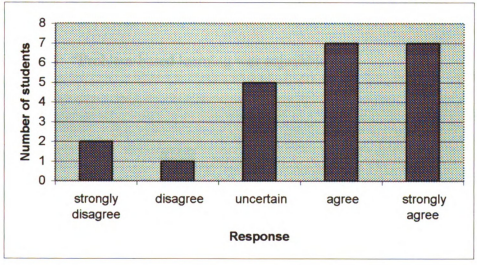


Figure 12: I was able to explain the laws of segregation and independent assortment after completing the sockosomes group activity.



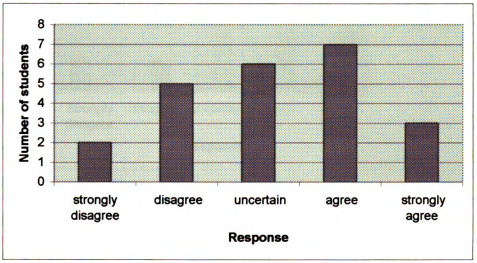
Students did feel more confident about the concepts learned during the Humans as Chromosomes activity and reported so on the post-survey (Figure 13).

Figure 13: "After participating in the meiosis game (hats), I was able to explain how the law of independent assortment can lead to differences between individuals in the population.

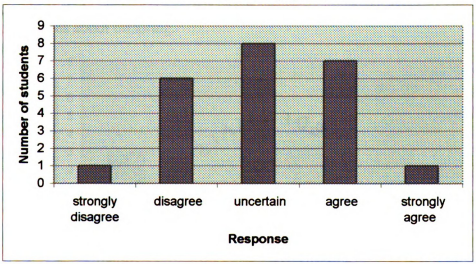


Students were also surveyed during the post-survey (Appendix B) about problem-based learning and the activities during the unit that were based upon this type of instruction. Students found that problem based learning was both somewhat challenging (Figure 14) and enjoyable (Figure 15).

Figure 14: "Problem-based learning was challenging."

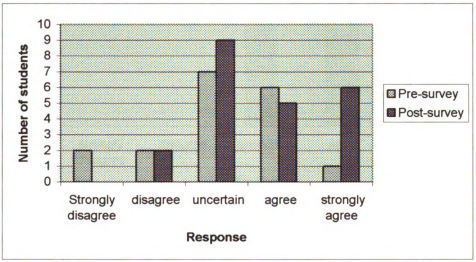


Graph 15: "Problem-based learning was enjoyable."



Comparison of data from the pre and post-survey (Appendix B) shows students did agree that problem-based learning was a more interesting approach to learning new concepts than more traditional methods (Figure 16).

Figure 16: Lessons designed as a problem to solve are/were more interesting than traditional worksheet problems.



Students responded favorably to individual problem-based learning activities when asked about them on the post-survey (Appendix B). Results of these questions are found in Figures 17, 18, and 19.

Figure 17: "After working through the problem based learning activity about Charlie the Cat, I was able to predict genotypes and work through Punnett squares to make predictions about offspring.

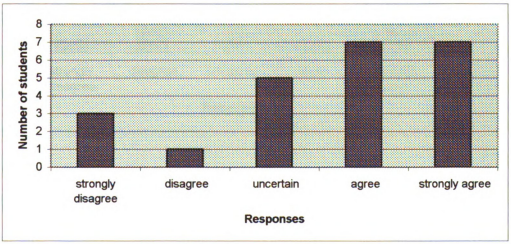


Figure 18: "After completing the problem based learning activity about Spot the cat, I was able to predict the genotypes and phenotypes of co-dominant traits in offspring in breeding problems."

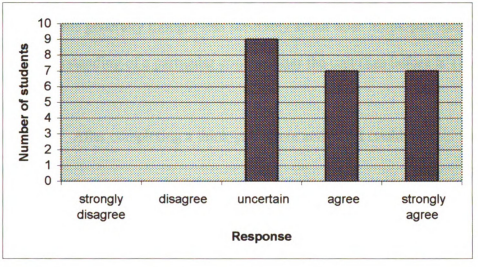
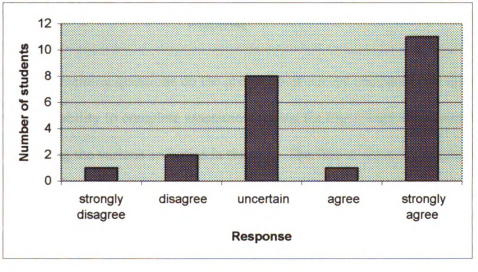
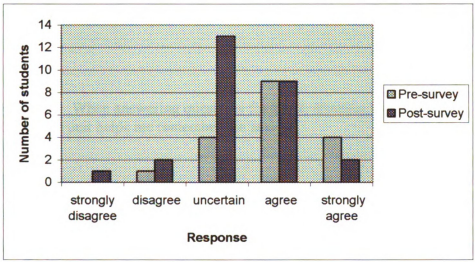


Figure 19: "After completing the problem based activity about orange cats, I was able to predict the genotypes and phenotypes for sex linked traits in offspring in breeding problems.



Think-pair-share (D. Walker, 1998) was also evaluated using the pre and post-survey. Because students were not familiar with the name of the method, this question was worded differently on the pre-test (Appendix B) than it was on the post-test (Appendix B). Students generally thought less favorably about how "think-pair-share" improved their understanding of a particular concept after the unit than before it (Figure 20).

Figure 20: After completing a think-pair-share activity, I could explain the concept being taught.



The remaining questions on the pre and post-survey (Appendix B) dealt with the students' ability to complete assessments using the knowledge they gained from completing the various activities in the unit. The first of these asked students to consider the difficulty experienced in completing the assessment questions following the activities (Figure 21). Students felt that they could use new knowledge to answer questions after an activity. They also felt that they could answer questions on a formal assessment by remembering what they had done during an activity as well (Figure 22).

Figure 21: "After completing activities from this unit, I was able to take what I learned and complete the analysis questions with little assistance."

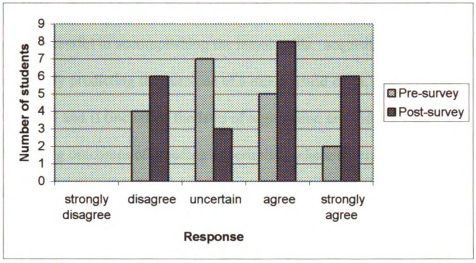
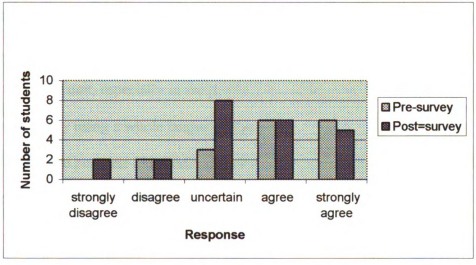


Figure 22: When answering questions for a test, thinking about activities I completed during the unit helps me remember the answer.



Information from these pre and post-surveys was used along with pre and post-test data to determine the effectiveness of the unit.

DISCUSSION

Data collected and analyzed during this unit generally support the conclusion that it was successful in accomplishing the major goals: acquisition of necessary vocabulary, accurately predicting the outcome of a monohybrid cross, describing the major events of meiosis I and II (including the laws of segregation and independent assortment), and predicting outcomes of breeding experiments where the trait is not a simple dominant/recessive.

Students were successful in learning necessary vocabulary and completing heredity problems using Punnett squares. Data found in Table 5 and Figure 3 support this conclusion. Students struggled with vocabulary after completing the "Bert and Ernie" activity, where these terms were first used. They continued to work with the terms through the problem-based activities and heredity problems. Students were never given a vocabulary quiz, per se. However, because the key terms were reinforced throughout the rest of the unit, especially in the problem-based learning activities, students learned the vocabulary using a whole language process.

On the post-test (Appendix B), I expected more students to be able to describe dominant and recessive alleles in their answers and for overall scores to increase for the question. This increase in points awarded would indicate advancement in understanding of the concept from middle school (a score of 1 on the rubric) (Appendix B) to a high school level (a score of 2 or 3 on the rubric). Students were able to apply these vocabulary terms correctly and scored well overall (Table 3). Application of these terms would indicate students understood the vocabulary and did not simply memorize definitions.

Analysis of vocabulary word acquisition occurring introduced later in the unit (haploid, diploid) was ambiguous (Table 4, Figures 1 and 2). Question twelve (Appendix B) dealt with vocabulary, specifically the term "haploid." Many students got the question right on the pre-test, while some missed it. Because this word was new, it would be best explained by guesswork on the students' part. This term would have been introduced during the activities about meiosis (Sockosomes, Meiosis and Fertilization, Reebops, and Humans as Chromosomes) (Appendix C). The term "diploid" was also introduced during these activities. Since most of the focus of instruction was on gamete formation, fertilization was not well covered, as indicated by this test item. It may also indicate that while students could pick out the definition from four choices, like question 12, they may not have really understood the meaning of the term. Although the terms were learned within the context of meiosis, students may have only remembered them as definitions. These terms were not learned and reinforced in the same way as the others from the Bert and Ernie activity. Perhaps a second activity like this one and more integration of the terms in the meiosis portion of the unit is needed.

Students struggled a bit more with the details of meiosis, in particular the laws of segregation and independent assortment and their role in variation (Figures 1 and 2, Table 4). Therefore, the unit was less successful than I had expected. My overall goal was to teach genetics within the context of meiosis and allow students to develop a clearer connection between the two. I wanted to seamlessly move between the two big ideas of meiosis and heredity in a way that allowed students to learn them as a single idea. However, this proved to be a bit more difficult than I had anticipated. Students needed more time to practice Punnett squares, which required more class time and additional

assignments for practice. Hoping not to fall into the same trap of having the students simply learn the algorithm of drawing out the Punnett squares without any connection to "origin" of the boxes, I attempted to tie our lessons on heredity with meiosis (Reebop and Humans as Chromosomes). Table 4 indicates some success in accomplishing this connection. However, when asked about details, students had difficulty in explaining the relationship between variation and the laws of segregation and independent assortment (Table 3 Figure 1)

The connection may not have been clear enough to the students. While students seemed to understand that the law of segregation resulted in genetic variation, they did not understand the law itself (Table 4). It is also possible that students knew that mitotic division results in genetically identical cells from a previous unit on mitosis and were able to pick this out of the choices available in question 16. In any case, students did not learn enough about the law of segregation during the Humans as Chromosomes or Sockosomes activities. In this way, my results were not unlike those of Stewart (1980, 1982).

Students typically enjoyed the active learning strategies employed in the unit (Figure 10). However, when asked about whether or not the activities helped them to understand how the law of independent assortment can lead to variation, the results where lower (Figure 11 and 12). The added dimensions of the different activities (moving around the room, permission to wear hats, and using food) may have proved too distracting for the students and affected their learning. The problem may lie in the word "enjoyment" here. While playing with the marshmallows was fun, most students did not draw the necessary connections at the conclusion of the activity.

While the problem-based learning activities were less enjoyable to them (Figure 15) than the Reebops, students self report better success at achieving the outcomes (Figures 17, 18 and 19). Completing fun activities also requires thinking, and new learned behavior.

However, problem-based learning had many benefits that were perhaps unrealized by students. Problem-based learning not only provided an opportunity to teach differently, but it allowed the opportunity to make the class more student centered. Discussions that occurred during class were substantive, and at times heated! During several of the PBL activities, students grouped up together to discuss the problems and work through a solution. "Now, look..." and "But if you try it this way..." could be heard as I walked around the room. I was impressed by the degree of ownership the students assumed in order to solve the problems. This took a little time to happen, however. Many of the students were used to teacher-centered activities and often wanted me to tell them the correct answer or if they were completing the assignment correctly. I had to learn to step back a bit and be more Socratic in my approach to their desire to hear the answer. Eventually, the students became more confident and began to take on the PBL's with very little need for me. After solving the sex-linked trait activity, a particularly difficult one, many of the students shouted out excitedly, "I figured it out! Can I share my answer when we go over it?" They were pleased with themselves and I was happy for them. It was, perhaps, the best part of the unit. Given the involvement level of students during each of the PBL activities, it is more than likely I will use them again when teaching genetics.

The structure of the PBL activities allowed for high levels of student motivation that did not necessarily occur during "think-pair-share activities." Students felt less confident about knowledge discussed after a think-pair-share than after a PBL (Figure 20). PBL had a sense of purpose to the conversation missing in a "think-pair-share" activity. "Think-pair-share" also seems to work better for shorter questions covering one particular point that can be addressed quickly. This may also have lead to students feeling less sure about the content. PBL involves longer conversations concerning many details that build upon each other.

One drawback to PBL, also described in the literature, is the fact that generally students who use it do not do as well on standardized testing than students who use more traditional methods (Evenson & Hmelo, 2000). Because PBL encourages method thinking instead of fact recall, students often do not have the chance to show what they have learned on a standardized test. While students did not take standardized tests during this unit, many did report that they felt it was less helpful to them in remembering information for the test (Figure 22). However, assessments following activities were accomplished easily by remembering what had occurred. When the assessments were more analytically in nature, students were confident that they could complete them using what they had learned (Figure 21). Perhaps this was due to the length of time between the activity and the assessment. Short standardized assessments at the conclusion of each PBL would be interesting to analyze to see if duration between the activity and assessment made a difference. It would also indicate whether or not my students had the same difficulties as those described by Evenson and Hmelo.

One of the questions on the pre and post-test (Appendix B) did not reveal much information about what students did or did not know. Rather, it revealed that some of the questions were not written clearly or were too abstract for students to understand. Students found the question itself was difficult to understand and they were not clear about the expectations for the answer. At issue was question 11. Students were asked to circle maternal chromosomes on a karyotype. While the statistical analysis indicated that the improvement on the question was significant (Table 3), anecdotally, the question did not allow for good results. Even after the unit was taught, many students still had difficulty answering this question. While the goal of the question was important, the question itself may have been too abstract. Even on the post-test, many students did not answer it correctly, or at all, simply because they didn't understand what to do with the picture. Several students asked during the test what they should do and some of the answers students gave revealed that they did not know exactly what the question required them to do. Fewer pairs of chromosomes in the karyotype and more explicit directions may be more helpful in the future.

In general, I believe that the unit successfully accomplished its goals and allowed students a unique opportunity to learn in real world, hands on way. The problem-based learning was the greatest strength of the unit, and something I will maintain in it. Students may not have "enjoyed" it in the way that they define it, but they found it challenging and learned well using it. It created substantive conversation and a student-centered learning environment that engaged the students' minds. Students were highly motivated by the method and found it challenging, but not overwhelming. It also allowed me an opportunity to coach, and I enjoyed that myself.

Other aspects of the unit provided learning experiences for my students and myself. While my students enjoyed using models of all sizes, they had a difficult time learning using them. Being busy with their hands may have been enjoyable, but their minds needed to be busy as well. It may also be that models are an abstract application of an idea. Perhaps the models themselves may have been the problem. Students may have enjoyed them (Figure 10), but perhaps did so without a sense of purpose. Being able to connect the model to the concept may have been the key factor missing. In the future, better management and clearer connections with the models may be needed.

Assessment may be the key to managing this aspect better. A group assessment after each activity may not only create a greater sense of responsibility to each student to keep an engaged mind, but it may also create a sense of responsibility to other students to get and give needed help. It may also help to break up some of the activities into pieces where one part is done and discussed before the next one is done, perhaps at a later time. In this way, the purpose of the models and the parallels between the models and the concepts they represent can be more clearly defined. Students could imitate me by moving the sockosomes on the table, but more information is needed to be sure that they know exactly why we move them as we do. Similarly, in Humans as Chromosomes, students could follow each other around the room without really understanding why. By breaking up the activities into segments, the students would have an opportunity to reflect and think about the information they had learned. In this way, they would learn the details better and would be able to apply the information to the segment that followed.

I would also like to improve the integration between meiosis and heredity. Students did quite well on the topic of heredity, but seemed to miss its connection with meiosis, as evidenced by assessment questions involving it (Table 4).

Having completed this study, I will continue to incorporate many of the activities into my heredity unit, especially problem-based learning. By refining the modeling activities to include more assessment, this unit could continue to improve and allow students to master the difficult concepts involved in heredity and meiosis.

APPENDIX – A

Parental Consent and Student Assent Form
Collection of Data for Master's Thesis

Dear Parents/Guardians and Students:

I am currently working toward completion of a Masters degree in Michigan State University's Division of Science and Mathematics Education (DSME). I have chosen to do my thesis work on increasing student comprehension in biology through activity based learning. Students will be learning about cell reproduction and heredity by participating in simulations, making models, acting, and using problem based learning labs.

In order to evaluate the effectiveness of this unit, data will be collected from students through pre and post-tests, lab questions, homework assignments, and surveys. With your permission, I would like to include your child's data in my thesis. Your child's privacy will be a foremost concern and will be protected to the maximum extent allowable by law. All data generated shall remain confidential. At no time will your child's identity be associated with the data nor will they be identified in any pictures taken to be used in the thesis presentation.

Participation in this study is voluntary. Your child will receive no penalty in regard to his/her grade should you deny permission for the use of his/her data. Your student will still be expected to participate in the classroom activities and complete assignments. However, your student's data will not be used in my thesis work. Consent forms will remain in a sealed envelope until after grades for the unit have been issued. At any time during the unit, you may request that your student's information not be included, and your request will be honored. There are no known risks associated with participation in this study. There will be no benefit to students in terms of extra credit or points for participating in this study.

If you are willing to have your student participate in this study, please complete the attached form and return it to me by October 2, 2006. If you have any questions about this study, please feel free to contact me by email at krawczykt@almont.k12.mi.us or by phone at 798-8595. Questions about the thesis project can also be directed to Dr. Merle Heidemann at DSME, 118 North Kedzie Laboratory, Michigan State University, East Lansing, MI, 48824, by phone: (517) 432-2152, ext 107, or by email: heidma2@msu.edu

If you have any questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact – anonymously, if you wish - Peter Vasilenko, Ph.D., Director of Human Research Protections, (517) 355-2180, fax (517) 432-4503, e-mail irb@msu.edu, or regular mail 202 Olds Hall, Michigan State University, East Lansing, MI 48824.

Thank you,

Tracie Krawczyk
Biology Teacher
Almont High School

Please fill out the following consent information and return it by October 2, 2006

I voluntarily agree to have _____ participate in this study.
(print student name)

Please check all that apply.

Data:

____ I give Mrs. Krawczyk permission to use data generated from my child's work in this class in this thesis project. All data from my child shall remain confidential.

____ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation.

Pictures:

____ I give Mrs. Krawczyk permission to use pictures of my child during her work on this thesis project. My child will not be identified in these mediums.

____ I do not wish to have my child's picture used at any time during this thesis project.

_____ _____
(Parent/Guardian signature) **(Date)**

I voluntarily agree to participate in this thesis project

_____ _____
(Student signature) **(Date)**

APPENDIX – B

Meiosis and Heredity Pre- and Post-Test

Write one or two sentences explaining how each of the following terms is related.

1. gene-allele-chromosome

For questions 4-6, read the following and answer the questions.
Your father has brown eyes (B) and straight hair (c). Your mother has blue eyes (b) and curly hair (C). You have brown eyes and curly hair.

2. Explain why you have eyes like your father and hair like your mother.

3. Is it possible for you to have a sibling with blue eyes and curly hair? Explain your answer.

4. How is it possible that two siblings could have the same parents but look different from each other?

5. If you were to have children, is it possible that they will have brown eyes and curly hair like yourself? Explain your answer.

6. What does meiosis have to do with a Punnett square?

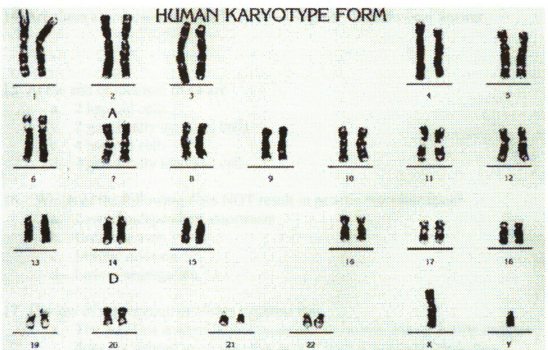
7. Which of the following is not an example of a trait that can be passed on?
   a. Missing limb due to amputation (parent's limb lost to amputation)
   b. Eye color
   c. Hair color
   d. Ability to roll tongue

8. What is a chromosome?

9. What is the purpose of meiosis?

10. Which of the following cells is NOT a gamete?
    a. Egg
    b. Sperm
    c. Pollen
    d. Leaf

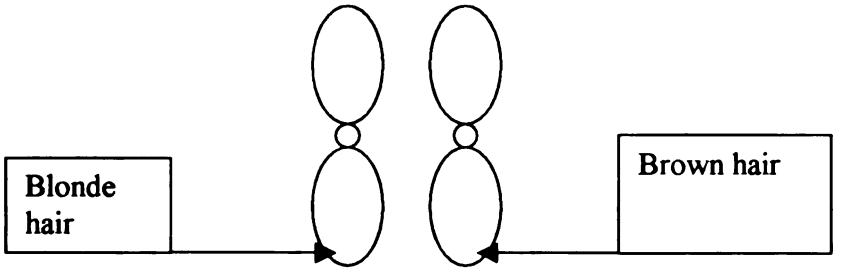
11. Circle the chromosomes from this human karyotype that came from the person's mother.



12. Gamete cells are haploid. This means that they have
    a. Both chromosomes from each homologous pair
    b. Neither of the chromosomes from each homologous pair
    c. One of the chromosomes from each homologous pair
    d. Some homologous pairs, but not others

13. When two gametes combine, they form a
    a. Diploid cell
    b. Haploid cell
    c. Triploid cell
    d. None of these

For question 14, refer to the following chromosomes:



14. Are these chromosomes considered homologous? Explain your answer.

15. At the end of meiosis, there are
    a. 2 haploid cells
    b. 2 genetically identical cells
    c. 4 haploid cells
    d. 4 genetically identical cells

16. Which of the following does NOT result in genetic recombination?
    a. Law of independent assortment
    b. Crossing over
    c. Mitotic division
    d. Law of segregation

17. The law of segregation of alleles explains that
    a. The way that a set of homologous chromosomes line up during meiosis does not depend upon the other sets of homologous chromosomes.
    b. The way that a set of homologous chromosomes line up during meiosis does depend upon the other sets of homologous chromosomes.
    c. Each chromosome in a set of homologous chromosomes separates from the other during meiosis
    d. Each chromosome in a set of homologous chromosome does not separate from the others during meiosis.

18. After the first division of meiosis,
    a. Sister chromatids have separated
    b. Cells contain a diploid number of chromosomes
    c. Homologous chromosomes have separated
    d. The gametes are ready to be fertilized.

19. A dominant allele
    a. Is found in the majority of the population
    b. Is only found in plants
    c. Is hidden when the recessive allele is present
    d. Is observed whether one or two copies are present

20. The phenotype of a recessive trait is only seen in an individual when
    a. One dominant allele is present
    b. One recessive allele is present
    c. Two dominant alleles are present
    d. Two recessive alleles are present

Suppose you crossed two pea plant, one (the mom) with the genotype Tt and the other (the dad) with the genotype tt. T is the allele for tall height and t is the allele for short height.

21. Which of the following are the **genotypes** of the plants?
    a. crossed
    b. Tall and short
    c. Tt and tt
    d. Pea plants

22. Which of the following are the **phenotypes** of the plants
    a. Crossed
    b. Tall and short
    c. Tt and tt
    d. Pea plants

23. The **genotype** of the mom is described as
    a. Heterozygous
    b. Homozygous recessive
    c. Homozygous dominant
    d. None of these

24. What would be the meiotic products for this trait be for the mom?
    a. T,T,t,t
    b. t,t,t,t
    c. T,T,T,t
    d. T,T,T,T

25. What would be the meiotic products for this trait for the Dad?
    a. T,T,t,t
    b. t,t,t,t
    c. T,T,T,t
    d. T,T,T,T

26. Which of these Punnett squares matches this cross between the parents?
♀ = mom ♂ = dad

a.

♀ \ ♂	t	t
T	tt	tt
T	tt	tt

b.

♀ \ ♂	T	t
t	tT	tt
t	tT	tt

c.

♀ \ ♂	t	t
T	Tt	Tt
t	tt	tt

d.

♀ \ ♂	T	t
T	TT	Tt
t	tT	tt

27. When the parent plants are crossed, what is the genotypic ratio of the punnett square?
    a. 1 TT: 2 Tt: 1 tt
    b. 0 TT: 2 Tt: 2 tt
    c. 2 TT: 0 Tt: 2 tt
    d. 0 TT: 4 Tt: 0 tt

28. When the parent plants are crossed, what is the phenotypic ratio of the punnett square?
    a. 2 tall: 2 short
    b. 4 tall: 0 short
    c. 0 tall: 4 short
    d. 3 tall: 1 short

29. If two heterozygous tall plants are crossed together, what is the genotypic ratio that results?
    a. 1 TT: 2 Tt: 1 tt
    b. 0 TT: 2 Tt: 2 tt
    c. 2 TT: 0 Tt: 2 tt
    d. 0 TT: 4 Tt: 0 tt

---

30. Cystic Fibrosis (F) is the most common lethal genetic disorder among Caucasians. The allele that causes this disorder is recessive. If a woman who is homozygous for CF has a child with a man who does not have the allele, what is the genotypic ratio that results?
    a. 1 FF: 2 Ff: 1 ff
    b. 2 FF: 2 Ff: 0 ff
    c. 2 FF: 0 Ff: 2 ff
    d. 0 FF: 4 Ff: 0 ff

31. Each of their children has a ___% chance of getting CF
    a. 100%
    b. 50%
    c. 25%
    d. 0%

---

32. A horse with red hair (S) and a horse with white hair (S') have a baby horse (foal) with red and white hairs mixed together. What is the genotype of the foal?
    a. SS
    b. SS'
    c. S'S'
    d. ss

33. Which of the following terms is used to describe this foal?
    a. recessive
    b. dominant
    c. incomplete dominance
    d. sex linked

---

34. A husband and wife have three boys and four girls. All of the girls have normal vision. Two of the boys are colorblind. Which of the following terms is used to describe this type of inheritance?
    a. Recessive
    b. Dominant
    c. Incomplete dominance
    d. Sex linked

35. Why are the boys the only children affected?

Student Pre Survey of Meiosis and Heredity Unit

For each question, use the following scale:

Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
1	2	3	4	5

1. I would rather use traditional lecture and book work activities to learn difficult concepts than models, problem based learning and other group activities.

2. Lessons designed as a problem to solve are more interesting than traditional worksheet problems.

3. When answering questions for the test, thinking about activities I completed during the unit helps me remember the answer.

4. When covering new material in class, I often help other students who have questions understand the material or ask other students for help with the material.

5. After talking to another student about material I have learned in class, I am able better able to explain the concepts.

6. I remember information from a lecture better when I can talk to other students about it.

7. Using models helps me to explain material covered in class better.

8. After completing a lab or activity, I am able to take what I learned and complete analysis questions with little assistance.

9. I complete or review notes at home to review the material covered in class.

10. I am able to correctly predict the outcome of a breeding experiment.

11. I am able to explain how parents pass on their traits to their offspring.

Student ID: _____

Student Post-Survey of Meiosis and Heredity Unit

For each question, use the following scale:

Strongly Disagree	Disagree	Uncertain	Agree	Strongly Agree
1	2	3	4	5

1. Participating in "Bert and Ernie Go to the Cattery" helped me to understand the terms phenotype, genotype, dominant, recessive, heterozygous, and homozygous.

2. Working through the group punnett square problems allowed me to recognize what I did and did not understand about punnett squares.

3. After working through the problem based learning activity about Charlie the Cat, I was able to predict genotypes and work through punnett squares to make predictions about offspring.

4. The Reebop activity (marshmallow creatures) was enjoyable.

5. After completing the Reebop activity, I was able to understand how the law of independent assortment can lead to differences in the population.

6. I was able to explain the laws of segregation and independent assortment after completing the group sockosome assessment activity.

7. After participating in the meiosis game (hats), I was able to explain how the law of independent assortment can lead to differences between individuals in the population.

8. Problem based learning was challenging.

9. Problem based learning was enjoyable

10. The problem based learning activities allowed me to show all that I had learned about heredity and meiosis.

11. After completing the problem based learning activity about Spot the Cat, I was able to predict the genotypes and phenotypes of codominant traits in offspring in breeding problems

12. After completing the problem based activity about orange cats, I was able to predict the genotypes and phenotypes for sex linked traits in offspring in breeding problems.

In general

13. I would rather use traditional lecture and book work activities to learn difficult concepts than models, problem based learning and other group activities

14. Lessons designed as a problem to solve were more interesting than traditional worksheet problems.

15. When answering questions for the test, thinking about how I solved the problem based learning activity (Charlie the Cat and The Cat Breeding Problem) helped.

16. During Think-Pair-Share activities, I either explained the material to other students or asked other students for help with the material.

17. After completing a Think-Pair-Share activity, I could explain concept being taught.

18. After completing activities during this unit, I was able to take what I learned and complete the analysis questions with little assistance.

19. I remember information from a lecture better when it includes Think-Pair-Share activities.

20. Using models (Reebops, sockosomes) helped me understand the connection between heredity and meiosis better.

21. Completing fill-in-the-blank notes at home helped me to review the material.

22. I am able to correctly predict the outcome of a breeding experiment.

23. I am able to correctly predict the outcome of a breeding experiment.

24. I am able to explain how parents pass on their traits to their offspring.

Pre and Post-Test Grading Rubric for Open-ended Questions

Item	3 points	2 points	1 point	0 points
1	Describe and connect all 3 terms	Describe and connect 2 terms	Describe 1 term/Generic answer	All incorrect/no response
2		Describe dominant/recessive alleles and explain how phenotypes appear	Mention only inheritance from one parent	All incorrect/no answer
3	Describe recessive traits and recombination	Describe dominant or recessive/relate to inheritance from distant relative	Mentions contribution of only one parent or "mixing" of genes	All incorrect/ No response
4	Describe recessive/dominant traits and recombination	Describe recessive traits or recombination	Only mention contribution of one parent	All incorrect/ no answer
5	Describe recessive/dominant traits and recombination	Describe recessive traits or recombination	Only mention contribution of one parent	All incorrect/ no answer
6		Connect meiosis, sex cells, and genetics	Mention "possibilities" but no connection to meiosis	All incorrect/ no answer
8		Piece of DNA containing genes	Piece of DNA	All incorrect/ no answer
9	Cell division of gametes where chromosome number is halved/ Variation in population	Division of gametes/ right number of chromosomes/passing of genes	Cell division	All incorrect/ no answer
11	One autosomal chromosome circled from each pair and X chromosome circled	One autosomal chromosome from each pair circled OR one sex chromosome circled	Some pairs with one circled	All incorrect/ no answer
13	"Yes" same genes in same loci	"Yes" same genes, do not mention loci	"Yes" without explanation	All incorrect/ no answer
35	Trait is sex linked and found on X chromosome	Trait is sex linked (but mention Y chromosome)	Related to sex, but not specific	All incorrect/ no answer

Answer key for Pre and Post-Test Objective Items

7. A
10. D
12. C
13. A
15. C
16. C
17. C
18. C
19. D
20. D
21. C
22. B
23. A
24. A
25. B
26. C
27. B
28. A
29. A
30. B
34. D

APPENDIX – C

Introduction to Mendelian Genetics: Lucky Stripes

Brainstorm: What is different about these cats that some have stripes and some don't?
Class ideas:

Laboratory Assignment
You and your lab partner will be studying the hairs of the famous cats to determine differences in the hairs of the striped and solid cats.

Directions:
Examine the hairs of the cats on the slides and draw a picture of each using first your eyes and then the microscope:

Name of Cat from which the hair came	When viewed with hand lens
Fizzy or Curly (Hair Type #1)	
Fizzy or Curly (Hair Type #2)	
Baby, Larry, or Moe	

Discussion:
1. What is different about the three types of hairs you observed?

2. What could account for these differences? (Why are some cats striped and other cats are not?)

3. Relate the differences between the hairs to our recent discussion of *genes* and *proteins*

Fizzy and Curly both have a trait called *agouti*. Agouti cats have hairs with individual stripes on them. Agouti is a dominant condition (A).

1. What would a cat that was heterozygous look like?

2. What would a cat that was homozygous recessive look like?

3. What is the genotype of Baby?

4. What is the genotype of Fizzy?

Bert and Ernie At the Cat Breeder
Written by T. Krawczyk and K. Joos

Ernie is in the apartment when Bert arrives home from grocery shopping.

Bert: Hey, Ernie. I'm back. They had 2 for one coupons for soy milk and organic asparagus at the grocery store. Wait...what's that?

Ernie: [peering into cardboard box] Hey, Bert. I found something we really need.

Bert: [suspiciously] Like when we REALLY needed that ceramic Elvis sculpture?

Ernie: No, this is even better! And I bet that you can't figure out what it is. I'll give you a hint...it starts with the letter C!

Bert: Ernie, you know how I hate cookie crumbs all over everything. The last time that Cookie Monster was here I was Swiffering for weeks.

Ernie: Naw, naw, Bert. It's not a cookie. This thing says, "meow!"

Bert: [hysterically] A CAT!! Are you crazy, Ernie! A CAT?! You didn't let that cat get to my pigeons did you! [running to window] Oh, poor Bernice -- she must be terrified by now. You can't keep a cat in an apartment that already has pet birds. Don't you know the food chain Ernie?

Ernie: Oh, Bert! Relax. Graycie is just as sweet as can be, aren't you? Look at her cute grey stripes. What a delightful phenotype.

Bert: What is a phenotype? It had better not be another cat!

Ernie: A phenotype is a word that means your physical characteristics.

Bert: Well, Ernie, that cat has to go. I am allergic.....achoo....to cat hair. That's MY phenotype. Come on, Grover can drive us back to the cattery.

Ernie and Bert arrive at the cattery with Graycie (still in the box).

Bert: Okay, Ernie. Now quick put her back where you found her.

Ernie: We can't just leave her here, Bert. Let's find someone here to talk to first. Oh, look...there's her parents, Fizzy and Fuzzy.

Bert: Fizzy and Fuzzy don't look like Graycie, Ernie. Are you sure that they are her parents?

Ernie: Sure, I'm sure. They both have stripes. Graycie has stripes. What's the problem?

Bert: Graycie has grey stripes and those cats have black stripes. Don't you think that Graycie would have black stripes, too?

Ernie: Bert, non dilute pigmentation is dominant over dilute pigmentation in cats. It has to do with the packing of the melanin in the hairs.

Bert: Did you fall and hit your head recently?

Ernie: My head is naturally football shaped, Bert. No, seriously, there was a terrific program on public television about this very thing. It was about Ge-NET-ics. Can you say that?

Bert: [rolling eyes] Ge-NET-ics.

Ernie: [cheerfully] Good, Bert! Melanin is the pigment in skin and hair that makes them the color that they are. Cats with dilute pigmentation have less pigment packed into the individual hairs. Some cats have the type of gene that causes dilute and others have the regular form of the gene.

Bert: So, is there something wrong with this cat, then?

Ernie: No, having less pigment is just something that makes cats different from each other. It's just like the way our heads are shaped differently.

Bert [under his breath] Well, I'm not so sure that's a good example, Ernie

Ernie What did you say, Bert?

Bert: Nothing. Hey, Ernie, I understand why this cat looks grey and why these cats look darker. But I don't understand why a cat with dark striped parents would have light stripes!

Ernie: Well, Bert, some forms of a gene are called "dominant" while others are called "recessive." In this case, dark stripes are a dominant trait. Graycie's parents have one of these dominant forms of the gene.

Bert: But Ernie, I STILL don't understand how Graycie ended up, well, gray.

Ernie: Recessive forms of the gene can be present in an individual, but not observable.

Bert: So, Fizzy and Fuzzy have hidden genes?

Ernie: Sort of. They are there, but you can't tell.

Bert: So let me get this straight...Fuzzy and Fizzy each gave Graycie the dilute form of the melanin pigment gene which made her look gray. But they are not grey because they also have the dominant trait at the same time. Right?

Ernie: Exactly, Bert.

Bert: So having the dominant and the recessive forms makes you look like the dominant form of the trait.

Ernie: Right. And having the two different forms is called "heterozygous." That's a genotype – the genetic make up of an organism.

Bert: And having only the recessive form of the gene makes the cat look like the recessive form of the trait. What would happen if the cat only has the dominant form of the trait?

Ernie: In this case, the cat would be dark also. Having two of the same type of the gene is called "homozygous."

Bert: Whoa! This stuff is really interesting, Ernie. I should start watching more public television. So Graycie's genotype must be homozygous for the recessive trait and her parents' genotype is heterozygous for the trait.

Ernie: Good job, Bert. Let's go home and watch some more educational programming. I have it recorded on TiVo. There's going to be a great show on the history of rubber duckies. Hee hee hee.

Bert: [sighing] Oh, Ernie. Let's go home. I need a cold soy milk.

Name: _____ **Hour:** _____

Cat Coat Color Genetics: Bert and Ernie Review Information

1. What did Bert find out from Ernie about dilute cats like Graycie? (What is different about their fur?)

2. What does the term **phenotype** mean?

3. Give an example from the story of a **phenotype**.

4. What does the term **genotype** mean?

5. Give an example from the story of a **genotype**.

6. What does the term **dominant** mean?

7. Give an example from the story of a **dominant** version of a gene.

8. What does the term **recessive** mean?

9. Give an example from the story of a **recessive** version of a gene.

10. What does the term **heterozygous** mean?

11. Explain why Fizzy and Fuzzy are considered to be **heterozygous**.

12. What does the term **homozygous** mean?

13. Explain why Graycie is considered to be **homozygous.**

14. Explain how it is possible for Graycie to be the kitten of Fizzy and Fuzzy.

Diamonds and PUURRLS

Problem #2: Graycie

Objectives:

1. Identify genotype and phenotype.
2. Describe the terms dominant and recessive
3. Describe the terms heterozygous and homozygous
4. Explain why an offspring may have different traits than its parents

Activity 1: Examine the difference between Fizzy and Graycie's hair:

Objective: To determine the difference between grey and black cat hair.

Directions:

1. Obtain a sample of each cat's hair
2. Examine each with a hand lens. Draw a picture and write a description of each in the chart below.

Cat	Sketch of hair	Written description of hair
Fizzy		
Graycie		

Discussion: Discuss with your partner what you found out about the differences between the two kinds of cat hair.

Statement: Write a two to three sentence statement below to describe the difference between the two kinds of hair.

_____

_____

_____

_____

Class Discussion: In the space below, include any information from the class discussion not included in your statement above.

Name: _____ Hour: ___

Problem #2: Graycie

Complete the following table with the characteristics of each cat:

Cat	Fizzy	Baby	Larry	Moe	Curly
Fur characteristic	**Agouti**	**Solid**			

Problem #1: Lucky Stripes Vocabulary Review

1. What is the **phenotype** of Baby?

2. What is the **phenotype** of Fizzy?

3. What would a cat that is **heterozygous** for agouti look like?

4. What would a cat that is **homozygous recessive** for the agouti trait look like?

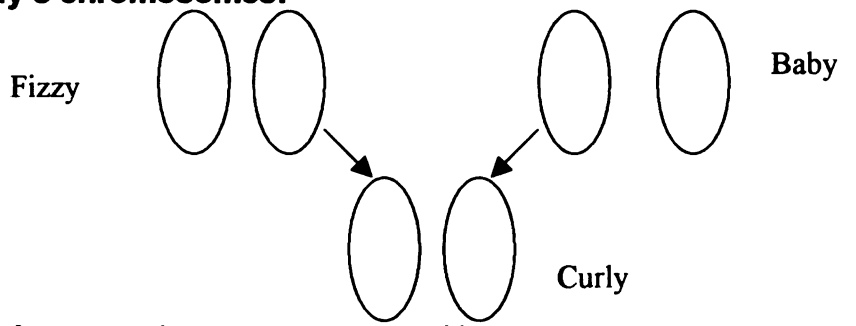
5. What is the **genotype** of Baby?

6. What is the **genotype** of Fizzy? (HINT: What are the phenotypes of the kittens: Larry, Moe, and Curly)

7. Explain how Curly ended up with stripes while Larry and Moe ended up solid black.

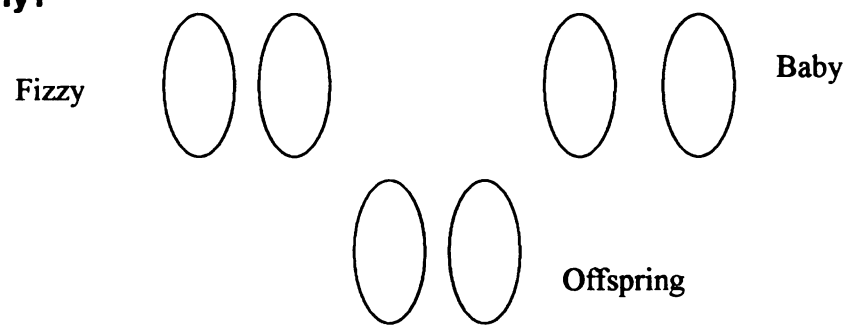
Punnett Squares Notes

Curly's chromosomes:



Dominant versions are represented by a _____.
Recessive versions are represented by a _____.

What are the other possible combinations for future brothers and sisters of Curly?



An easier way to do this? Punnett Squares

- Each row/column represents a version of the gene each parent could donate.
- The result is a chart with all of the possible combinations for one offspring.

Mom → Dad ↓	a	a
A		
a		

1. How many different combinations are there? _____
2. What are the different combinations possible?

   _____

3. Identify the phenotypes that match each combination:

_____

4. If Fizzy and Baby had another kitten, what are the chances that it would have dark stripes?

   _____

REMEMBER:

- the chart represents the possibilities for each kitten.
- The possbilities start over each time a new kitten is created
- The next kitten could have striped OR solid fur. It does not have to be striped just because two siblings are already solid and one is already striped.

Let's review the Graycie problem using Punnett Squares
This will be a Think-Share-Pair activity.

Fizzy and Fuzzy are black agouti cats. They have a kitten named Graycie, who is a grey agouti cat. Dilute fur is recessive to non-dilute fur. Complete a Punnett square to show that Graycie could be the kitten of Fizzy and Fuzzy.

First, figure out the phenotypes and genotypes of the parents and Graycie:

	Graycie	Fuzzy	Fizzy
phenotype			
genotype			

Next, complete the Punnett Square:

Fuzzy → Fizzy ↓		

What are the chances that Fizzy and Fuzzy could have a kitten with dilute fur?

T-P-S: How do we know for sure that Fizzy and Fuzzy are both heterozygous?

Homework Assignment: Complete the Punnett square story problem set. Be sure to look back at your notes to help you with vocabulary.
This will be due TOMORROW.

Sockosomes

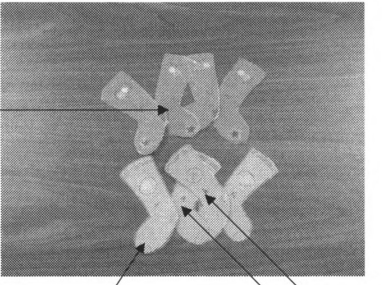
Sockosomes are construction paper "socks" that are used to represent chromosomes and chromatids to learn about Meiosis I and II.

Each sockosome set is decorated differently with one allele labeled with letters. Other alleles are represented by the decorations on the sockosome.

Sockosomes each have a small piece of Velcro to attach sister chromatids together.

Students practice lining up and separating the sockosomes on their tables to represent the divisions that occur during Meiosis I and II.

To increase durability, the sockosomes are covered in contact paper.



Problem #4: Charlie The Cat

The Diamonds and PUURRLS Cattery has a new champion cat named Shiver-Me-Timbers III (nicknamed Charlie). He is a cat with solid dark fur. When cats are shown, paperwork must be provided to prove lineage. The paperwork for Charlie the Cat says that his parents are Cloud (Dad) and Marshmallow (Mom). Both cats are pure white.
Two days after the championship, the owner of the second place cat challenged the pedigree of Charlie the Cat. She contends that Cloud and Marshmallow can't possibly be Charlie's parents.

Is the she being a sore loser, or is she pointing out a cheater?!!!
What do you think?

Goals for this problem:

1. Determine the possible genotypes of the parents and of Charlie
2. Determine whether it is possible for Charlie to be the kitten of Cloud and Marshmallow.

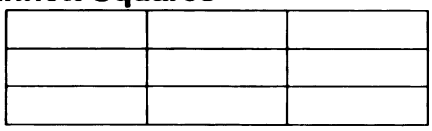
Questions to get started with:

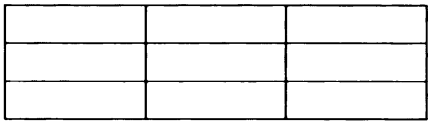
1. What are the genotypes/phenotypes of the cats involved?
2. Which genotypes cause each of the phenotypes?
   To continue, you will need to ask Mrs. K for research materials.
   You may consult with other groups during the research portion of the problem.
3. What are the dominant/recessive versions of each of the traits?

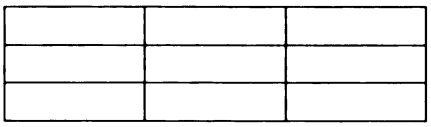
	Cloud	Marshmallow	Charlie
phenotype			
genotype			

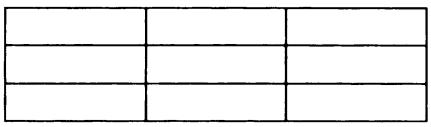
Research information

Punnett Squares









Results:
What are the possible genotypes of Charlie and his parents?

Is it possible for Charlie to be the kitten of Marshmallow and Cloud? Explain your answer.

Cat Coat Color Genetics

Adapted from: http://sirlou.best.vwh.net/catgenetics.html

Courtesy of Dr. Merle Heidemann, Michigan State University, DSME

The Color-Conformation Genes

The color-conformation genes determine the color, pattern, and expression of the coat. Since these characteristics are among the most important of the cat's features, at least from a breeding point of view, more emphasis is given the color conformation genes than the others. These genes fall into three logical groups: those that control the color, those that control the pattern, and those that control the color expression. Each of these groups contains several differing but interrelated genes.

The Orange-Making Gene

The second of the genes controlling coat color is the orange-making gene. This gene controls the conversion of the coat color into orange and the masking of the agouti gene and comes in two alleles: nonorange and orange.

The non-orange allele, "o", is wild and allows full expression of the black or brown colors. The orange allele, "O", is mutant and converts black or brown to orange and masks the effects of the non-agouti mutation of the agouti gene (all orange cats are tabbies). This gene is sex-linked -- it is carried on the "X" chromosome beyond the limit of the "Y" chromosome. Therefore, in males there is no homologous pairing, and the single orange-making gene stands alone.

As a result there is no dominance effect in males: they are either orange or non-orange. If a male possesses the non-orange allele, "o", all colors (black, dark brown, or light brown) will be expressed. If he possesses the orange allele, "O", all colors will be converted to orange.

In females there is homologous pairing, one gene being carried on each of the two "X" chromosomes. These two genes act together in a very special manner because of X inactivation. If the female is homozygous for non-orange, "oo", all colors will be expressed. If she is homozygous for orange, "OO", all colors will be converted to orange. It is when she is heterozygous for orange, "Oo", that interesting things begin to happen: through a very elegant process, the black-and-orange tortoiseshell or brindled female is possible.

Shortly after conception, when a female zygote is only some dozens of cells in size, a chemical trigger is activated to start the process of generating a female kitten. This same trigger also causes the zygote to "rationalize" all the sex-linked characteristics, including the orange-making genes. In this particular case, suppression of one of the orange-making genes in each cell takes place in a not-quite-random pattern (don't worry about this). Each cell will then carry only one orange-making gene.

Since the zygote was only some dozens of cells in size at the time of rationalization, only a few of those cells will eventually determine the color of the coat (the orange-making genes in the other cells will be ignored). If the zygote were homozygous for non-orange, "oo", then all cells will contain "o", and the coat will be non-orange. Likewise, if the zygote were homozygous for orange, "OO", then all cells will contain "O", and the coat will be orange. If, however, the zygote were heterozygous, "Oo", then some of the cells will contain "O" and the rest of the cells will contain "o". In this case, those portions of the coat determined by "O" cells will be orange, while

those portions determined by "o" cells will be non-orange. Voila! A tortoiseshell cat!

A female kitten has two "X" chromosomes, and therefore two orangemaking genes, one from each parent. Assuming for the sake of discussion an equal likelihood of inheriting either allele from each parent -- an assumption that is patently false, but used here for demonstration only -- then one quarter of all females would be non-orange, one quarter would be orange, and one-half would be tortoiseshell. A male kitten, on the other hand, has only one "X" chromosome, and therefore only one orange-making gene. Keeping the same false assumption of equal likelihood, then one-half of all males would be non-orange and one-half would be orange. This means that there would be twice as many orange males as females if our assumption were correct.

Since a male has only one orange-making allele, there cannot be a male tortie. An exception to this rule is the hermaphrodite, which has an "XXY" genetic structure. Such a cat can be tortie, since it has two "X" chromosomes, but must invariably be sterile. In fact, despite the presence of male genitalia, a hermaphrodite is genetically an underdeveloped female, and may have both ovaries and testes, with either fully functional.

The Color-Density Gene

The third and last of the genes controlling the coat color is the color-density gene. This gene controls the uniformity of distribution of pigment throughout the hair and comes in two alleles: dense, "D", and dilute, "d". The dense allele, "D", is wild, is dominant, and causes pigment to be distributed evenly throughout each hair, making the color deep and pure. A dense coat will be black or orange. The dilute allele, "d", is mutant, is recessive, and causes pigment to be agglutinated into microscopic clumps surrounded by translucent unpigmented areas, allowing white light to shine through and diluting the color. A dilute coat will be blue (gray) or cream.

Geno	Sex	Color
ooDD	Female	Black
ooDd	Female	Black
oodd	Female	Blue
OoDD	Female	Blk/Red
oYDD	Male	Black
OYDD	Male	Red
OoDd	Female	Blk/Red
oYDd	Male	Black
OYDd	Male	Red
Oodd	Female	Blu/Crm
oYdd	Male	Blue
OYdd	Male	Cream
OODD	Female	Red
OODd	Female	Red
OOdd	Female	Cream

The dilute colors are rarer (hence generally more prized) because they are recessive. Note that although tortoiseshell females are two-color they introduce no new colors.

The Albinism Gene

The first of the color-conformation genes affect coat pattern is the albinism gene. This gene controls the amount of body color and comes in three alleles: full color, "C", blueeyed albino, "ca", and albino, "c". The full color allele, "C" is wild, is dominant, and produces a full expression of the coat colors. This is sometimes called the nonalbino allele.

The blue-eyed albino allele, "ca", is mutant, is recessive to the full color allele and dominant to the albino allele, and produces a nearly complete albinism with a translucent white coat and very washed-out pale blue eyes.

The albino allele, "c", is mutant, is recessive to all others, and produces a complete albinism with a translucent white coat and pink eyes.

The albanism genes combine in some rather interesting ways:

	C	ca	c
C	full color	full color	full color
ca	full color	B-E Albino	B-E Albino
c	full color	B-E Albino	Albino

The Agouti Gene

The next gene controlling the pattern of the coat is the agouti gene. This gene will control ticking and comes in two alleles: agouti, "A", and non-agouti, "a". The agouti allele, "A", is wild, is dominant, and produces a banded or ticked (agouti) hair, which in turn will produce a tabby coat pattern. The non-agouti allele, "a", is mutant, is recessive, and suppresses ticking, which in turn will produce a solid-color coat. This gene only operates in conjunction with the non-orange allele of the orangemaking gene and is masked by the orange allele of the orange-making gene.

The Tabby Genes

The last of the genes affecting the coat pattern is the tabby gene. This gene will control the actual coat pattern (striped, spotted, solid, etc.) and comes in two alleles: mackerel or striped tabby, "T", and blotched or classic tabby, "tb". The mackerel-tabby allele, "T", is wild, is co-dominant with the spotted tabby allele and dominant to the classic-tabby allele, and produces a striped cat, with vertical non-agouti stripes on an agouti background. This is the most common of all patterns and is typical grassland camouflage, where shadows are long and straight.

A spotted tabby is genetically a striped tabby with the stripes broken up by polygene influence. There is no specific "spotted-tabby" gene. This spotted coat is a typical forest camouflage, where shadows are dappled by sunlight shining through the trees. Do not confuse the spots of our domestic cats with the rosettes of the true spotted cats: entirely different genes are involved.

The blotched- or classic-tabby allele, "tb", is recessive to the mackerel-tabby allele and will produce irregular non-agouti blotches or "cinnamon-roll" sworls on an agouti background. When the "cinnamon-rolls" are clean and symmetrical, and nicely centered on the sides, a strikingly beautiful coat is achieved.

The Spotting Gene

The next gene controlling color expression is the white-spotting gene. This gene controls the presence and pattern of white masking the normal coat pattern, and has four alleles: non-spotted, "s", and spotted,"S". The non-spotted allele, "s", is wild, is recessive, and produces a normal coat without white.

The spotted allele, "S", is mutant, is dominant, and produces white spotting which masks the true coat color in the affected area. This is a variably-expressed allele with a very wide expression range: From a black cat with one white hair to a white cat with one black hair.

Unlike the white gene or the albinism gene, the white-spotting gene does not affect eye color: if your all white cat has green eyes, it is most definitely a colored cat with one big white spot all over.

The Dominant-White Gene

The final gene controlling color expression is the dominant-white gene. This gene determines whether the coat is solid white or not, and comes in two alleles: non-white, "w", and white, "W". The non-white allele, "w", is wild, is recessive, and allows full expression of the coat color and pattern.

The white allele, "W", is mutant, is dominant, and produces a translucent all-white coat with either orange or pale blue. Blue-eyed dominant-white cats are often deaf, orange-eyed cats occasionally so. Interestingly, a white cat may be odd-eyed, having one blue and one orange eye. Such a cat is often deaf on the blue side.

It is important to remember that, genetically speaking, white is not a color, but rather the suppression of the pigment that would normally be present. A heterozygous white cat can an often does produce colored kittens, sometimes with no white at all.

The Standard Solid Colors

The solids form the basis for all other colors in nomenclature and genotypes. The subtle differences possible in blues (grays) has made this one of the most popular colors among breeders, with several breeds being exclusively blue. Blues, regardless of pattern, are often referred to as "dilutes."

Since the orange allele of the orange-making gene also masks the nonagouti allele of the agouti gene, red and cream solids are genetically identical to red and cream tabbies. Careful selective breeding has made cause the non-agouti areas (the stripes) to widen and overlap, effectively canceling the paler agouti background and obscuring the tabby pattern. A generation or two of random breeding, however, and the stripes will return.

The patched solids, solid-and-whites or bi-colors, are formed by adding the white-spotting gene, "S*", to the solids. Cats with less than 50% white are expected to be Ss, while those with more than 50% white are expected to be SS.

The tortoiseshells or torties are formed by combining both the dominant and recessive sex-linked orange genes, "Oo", with the solids. Because of the sex-linking of the orange genes, the tortie is always female. A tabby pattern may be visible in the orange areas, with any tabby pattern being permitted. In some individuals, the agouti and non-agouti orange areas may offer such contrast as to produce a false tri-color (black-orange-cream).

The patched tortoiseshells or calicos are formed by combining both the dominant and recessive sex-linked orange-making genes, "Oo", to the

solids and adding the white-spotting gene, "S*". Like the torties, the calicos are always female, and like the patches, any whitespotting pattern is permitted.

Color	Genotype	Usual eye color
Black	ooD* C*aa** ssww	cpr org grn
Blue	oodd C*aa** ssww	cpr org grn
Red	OOD* C***T* ssww	cpr org
Cream	OOdd C***T* ssww	cpr org
Black patch	ooD* C*aa** S*ww	cpr org grn
blue patch	oodd C*aa** S*ww	cpr org grn
red patch	OOD* C***T* S*ww	cpr org
cream patch	OOdd C***T* S*ww	cpr org

The Standard Tabby Colors

The tabbies are formed by adding the agouti gene, "A*", to the solids. This causes the otherwise solid color to show the pattern dictated by the tabby gene: light and dark stripes (mackerel allele, "T*") or blotches (blotched allele, "tbtb").

The brown tabby corresponds to the black solid: sufficient undercoat color shows in the agouti areas to provide a brownish cast. When in mackerel pattern, this is the "all wild" genotype, and represents the natural state of the cat.

The red tabby, when in mackerel pattern, presents an alternate stable coat often found on feral domestic cats, usually as a pale ginger. The patched tabbies or tabby-and-whites are formed by adding the white spotting gene, "S*", to the tabbies. Like the patched solids, any white spotting pattern is permitted. The tabby-tortoiseshells or torbies are formed by combining both the dominant and recessive sex-linked orange genes, "Oo", with the tabbies colors. Like the torties, the torbies are always female.

Color	Genotype	Usual eye color
tortie	OoD* C*aaT* ssww	cpr org
blue tortie	Oodd C*aaT* ssww	cpr org grn
calico	OoD* C*aaT* S*ww	cpr org
blue calico	Oodd C*aaT* S*ww	cpr org grn
brown tabby	ooD* C*A*T* ssww	cpr org yel hzl
blue tabby	oodd C*A*T* ssww	cpr org yel hzl
red tabby	OOD* C***T* ssww	cpr org yel hzl
cream tabby	OOdd C***T* ssww	cpr org yel hzl
brown patched tabby	ooD* C*A*T* S*ww	cpr org yel hzl
blue patched tabby	oodd C*A*T* S*ww	cpr org yel hzl
red patched tabby	OOD* C***T* S*ww	cpr org yel hzl
cream patched tabby	OOdd C***T* S*ww	cpr org yel hzl
torbie	OoD* C*A*T* ssww	cpr org yel hzl
blue torbie	Oodd C*A*T* ssww	cpr org yel hzl
torbico	OoD* C*A*T* S*ww	cpr org yel hzl
blue torbico	Oodd C*A*T* S*ww	cpr org yel hzl

The patched tabby-tortoiseshells, or patched torbies or torbicos, are formed by combining the dominant and recessive orange-making genes, "Oo", with the standard tabbies and adding the white spotting gene, "S*", to the torbie colors. Like the patched solids, any whitespotting pattern is permitted.

The Whites

White is not a color, but rather a masking of the color genes resulting in an absence of color. There are four ways a cat can have an all white coat: be full-spotted white, be dominant white, be blue-eyed albino, or be albino. Each of these ways is genetically different. The full-spotted white coat comes from extreme expression of the white spotting gene in the dominant homozygote, SS, masking all colors and patterns. This coat may have a few non-white hairs, especially on a kitten. The eyes will be the proper color for the masked "true" coat colors, and may be anything except dominant-white blue, albino blue, or pink.

The dominant white coat comes from expression of the dominant-white gene, "W*", masking all colors and patterns. The eyes are always orange, dominant-white blue, or odd (one of each). The blue-eyed albino comes from expression of the blue-eyed albino allele of the albino gene, "ca*", masking all colors and patterns. The eyes are always albino blue. The albino coat comes from expression of the albino allele of the albino gene, "cc", masking all colors and patterns. The eyes are always pink.

Color	Genotype	Usual eye color
full-spotted white	****** ****** **SS**	not wbl/abl/pnk
dominant white	****** ****** ****W*	org wbl odd
blue-eyed albino	****** ca***** ******	alb
albino	****** cc**** ******	pnk

Meiosis and Fertilization

Meiosis

Mitosis gives rise to almost all the cells in the body. A different type of cell division called **meiosis** gives rise to sperm and eggs. During **fertilization** the sperm and egg unite to form a single cell called the **zygote** which contains chromosomes from both the sperm and egg. The zygote undergoes mitosis to begin development of the human embryo which eventually becomes a baby.

a. In humans, how many chromosomes should a zygote have, so the baby's body cells will each have a normal set of chromosomes? _____

b. If the sperm and egg each contribute all of their chromosomes to the zygote, how many chromosomes should each sperm and egg have to produce a normal zygote? _____

c. Suppose sperm and eggs were produced by mitosis. If a sperm of this type fertilized an egg of this type, how many chromosomes would the resulting zygote have? _____

d. Why would this be a problem?

e. How could this problem be avoided?

Meiosis reduces the number of chromosomes by half, so in humans each sperm and each egg has only 23 chromosomes, including one chromosome from each pair of homologous chromosomes. Therefore, fertilization results in a zygote which has 23 pairs of homologous chromosomes, one in each pair from the sperm and one from the egg. When the zygote undergoes mitosis to begin to form an embryo, each cell will have the normal number of 46 chromosomes.

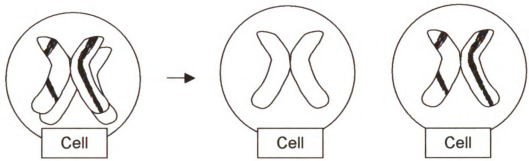
Cells that have two copies of each chromosome (i.e. cells that have pairs of homologous chromosomes) are called **diploid** cells. Most of the cells in our bodies are diploid cells. Cells that only have one copy of every chromosome are called **haploid** cells.

f. Which types of cells in our bodies are haploid?

Meiosis consists of two cell divisions, **meiosis I** and **meiosis II**. This reduces the chromosome number by half and produces four haploid daughter cells (instead of two diploid daughter cells as in mitosis).

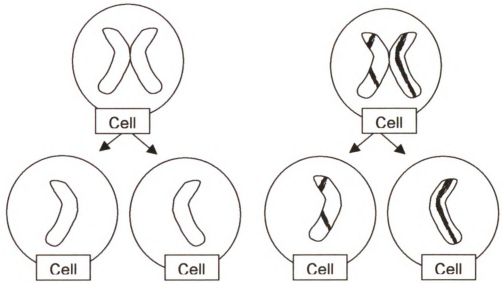
Meiosis I

Meiosis I is different from mitosis because homologous chromosomes line up next to each other and then separate, as shown below. This produces daughter cells with half as many chromosomes as the parent cell, i.e. haploid cells. Notice that each of the daughter cells has a different chromosome from the homologous pair of chromosomes. This means that the alleles in each daughter cell are different.



Meiosis II

Meiosis II is like mitosis. Each chromosome splits in half, so that each daughter cell inherits one chromatid from each chromosome.



Using your sockosomes, go through each step of meiosis until you are confident that you understand the difference between Meiosis I and Mitosis and the difference between Meiosis I and Meiosis II.

Group Assessment

For this activity, you will be working with the members of the group at your table. First, practice reviewing the steps of meiosis together. Make sure that everyone in your group can explain all of the steps.

Your grade on this assessment will be a group grade. Each person will be asked a different question about the process of meiosis. The response to these questions will determine the group's grade on this assessment.

Now, use your sockosomes to model meiosis in a cell which has two pairs of homologous chromosomes. Find another group that has the two different versions of the gene you do not have, either albinism (**A** for pigmented skin and **a** for albinism) or thumb bending (**H** for straight thumb and **h** for the hitchhiker's thumb). Put these four sockosomes in a pile in the middle of a circle which represents a cell. This pile of sockosomes will represent the two pairs of homologous chromosomes, each with the DNA copied, so the cell is ready to undergo meiosis. Model the steps in meiosis.

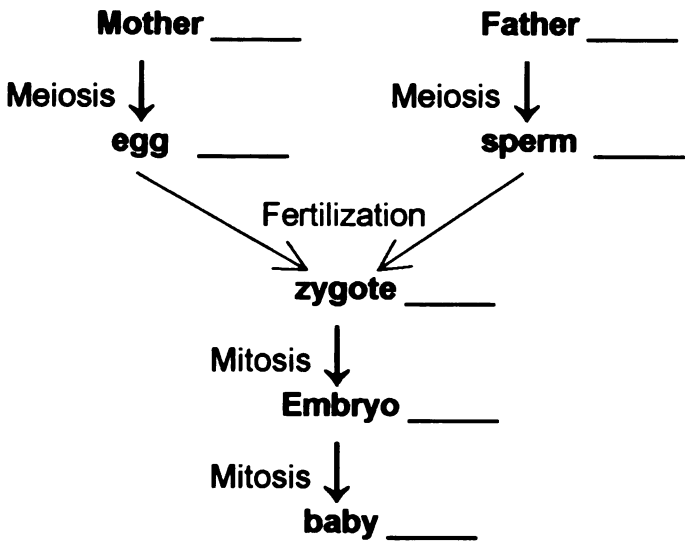
g. List all of the different combinations of alleles that can be observed in the daughter cells (sperm or eggs) produced by meiosis in the chart below.

Combinations of Albinism and Thumb Bending Alleles

h. Describe the differences between the mother cell that undergoes meiosis and the daughter cells produced by meiosis.

Fertilization

a. The following diagram provides an overview of the information covered thus far. Review the diagram, and fill in the correct number of chromosomes per human cell in each blank.



Now we will consider fertilization in more detail, in order to provide a basis for understanding **genetics**. Events during meiosis and fertilization determine the genetic makeup of the zygote, which in turn determines the genetic makeup of the baby that develops from the zygote.

You already know that sisters or brothers can have different characteristics, even when they have the same parents. One major reason for these different characteristics is that the processes of meiosis and fertilization result in a different combination of genes in each child.

To begin to understand this genetic variability, you will model meiosis and fertilization for a very simplified case where there is only one pair of homologous chromosomes per cell, and the two homologous chromosomes carry different alleles of the same genes. One person in your group will be the mother with two sockosomes that are the same color that represent the two maternal homologous chromosomes with different alleles of the same labeled gene. Another person will be the father with two sockosomes that are a different color than the mother's carrying the same two labeled alleles as the mother's sockosomes. (The different colors for the mother's and father's sockosomes represent the fact that, although the labeled alleles are the same for the mother's and father's chromosomes, there are many genes on each chromosome and the mother's and father's chromosomes will have different alleles for many of these genes.)

b. In this simple example, how many different types of eggs will be produced by meiosis? _____

c. How many different types of sperm will be produced by meiosis? _____

The different types of sperm can fertilize the different types of egg to result in zygotes with different combinations of chromosomes from the mother and the father. Fertilization can be demonstrated by having the mother and father each contribute one chromatid from one of their sockosomes, representing one chromosome from the egg and one chromosome from the sperm. Try to produce as many different types of zygotes as you can by pairing each type of sperm with each type of egg. To demonstrate fertilization, it works best to lay the chromosomes out on the table, so you can more easily see the multiple different possible combinations.

d. How many different types of zygotes can be produced by fertilization in this simple case?

e. What different combinations of the labeled alleles can be observed in the zygotes?

A pair of human parents could produce a great many more different genetic combinations than observed in this simplified example. For example, humans have 23 pairs of homologous chromosomes, so many, many different combinations of chromosomes can be found in the eggs or sperm produced by one person, and the different combinations of eggs from one mother and sperm from one father could produce zygotes with approximately 70 trillion different combinations of chromosomes! You can see why no two people are genetically alike, except for identical twins who are derived from the same zygote.

Questions

1. How many chromosomes are there in a human skin cell produced by mitosis?

   _____

   How many chromosomes are there in a human sperm cell produced by meiosis?

   _____

2. Describe the differences between mitosis and meiosis.

3. What are the similarities between mitosis and meiosis?

Name: _____ Hour: _____

The Reebop Family: An Activity In Meiosis and Genetic Variation

Reebops are an imaginary species that are prolific and require minimal care. In this activity you are to simulate the process of Reebop meiosis and fertilization. The activity will result in the construction of Reebop offspring. You are to sort Mom and Dad Reebop chromosomes using the concepts of meiosis in forming the gametes, decode the chromosomal code found on the baby. After the Reebops are born, the Reebop siblings will be assembled together in the nursery to be analyzed. Chromosomal analysis of this unusual species has revealed that Reebops have 7 pairs of chromosomes, a total of 14 chromosomes.

Objectives:

A. To simulate a model of meiosis
B. To interpret the results of the role of meiosis in sexual reproduction

Procedure:

1. Meet Mom and Dad Reebop. They are on the front desk. Note their general anatomy.
2. On your desk is an envelope that contains a copy of both Mom and Dad's chromosomes. Remove the chromosomes from the envelope and separate them by sex. In this simulation, Dad Reebop's chromosomes are blue and Mom Reebop's chromosomes are pink. Of course, this is not true in real organisms.
3. Your partner will get the 7 pairs of chromosomes of one sex and you will get the 7 pairs of the other sex. Pair up each set of chromosomes.
    a. *Are the parents haploid or diploid?* _____. *Explain.*

    b. *How did you know how to pair up the chromosomes? (2 ways)*

    c. *Write the term that describes these paired chromosomes.*
    _____
4. You will simulate the results of meiosis by forming gametes from Mom Reebop's and Dad Reebop's chromosomes. After the homologous chromosomes are lined up you will flip a coin to determine which of mom's chromosomes are segregated in to the gamete. For the first pair of chromosome, choose the chromosome on the left if you flip heads, and choose the chromosome on the right if you flip tails. Be sure to segregate mom and dad's chromosomes separately. Put this chromosome to the side and return the chromosome not chosen to the envelope. Repeat for pair two. Repeat until all of the chromosome pairs have been used.
5. The other person should repeat the process in #4 for dad's chromosomes.
6. Put the two gamete chromosomes together.
    a. *What process does joining the gametes simulate?*

    b. *What do we call the fertilized egg?*

    c. *Is the fertilized egg haploid or diploid?*

7. **Congratulations!! A baby Reebop has just been born.**

Each baby should have _____ pairs of chromosomes, one of each pair from _____ and the other from _____.

8. Turn the Baby Reebop's chromosomes over and use the key to decode its chromosomes code as you construct this new offspring.

9. Put your finished Baby Reebop in the nursery with its siblings and compare the babies.
   a. *Are any two Baby Reebops alike?*

   b. *Why do they differ?*

   c. *What makes identical twins identical?*

   d. *Does each parent contribute the same amount of genetic information to a child?*

   e. *Why do siblings in a given family look similar yet are all different?*

Data and Results

Allele	My Baby's Genotype	My Baby's Phenotype
A/a		
Q/q		
E/e		
D/d		
M/m		
T/t		
L/l		

Class Data	XX	Xx	Xx	Genotypic Ratio	Phenotypic Ratio

Challenge Questions:.

1. Give an example of a genotype and a phenotype from this activity.

2. Would it be more likely that two siblings would look alike if reproduction occurred by mitosis or meiosis. Explain.

3. How do the Mom and Dad Reebops compare to one another? Based upon observation, can you tell if they're genetically identical? Why or why not?

4. When you choose one chromosome from Mom and one from Dad and put them in the baby pile, what processes does this action represent in actual reproduction?

5. Mom and Dad Reebop are heterozygous for every trait. This means that they are hybrids/purebred (circle one)

"Human Chromosomes" -- Teacher Edition

Adapted from Joesph P. Chinnici, Joyce W. Yue, and Kieron M. Torres "Students as 'Human Chromosomes' in Role-Playing Mitosis & Meiosis." *The American Biology Teacher*, 66(1): 35-39.

Objectives:

1. **Explain these terms: homologous chromosomes, sister chromatids, genome, diploid, haploid, zygote, allele**
2. **Explain how homologous chromosomes segregate and non-homologous chromosomes assort independently during meiosis**
3. **Predict the role of meiosis in sexual reproduction.**

Materials:

1. baseball cap (or other kind of hat)
2. 2 plastic nametags (one with letter inserted, one with 4X4 in. cardboard piece attached)
3. "Guide to being a human chromosome"

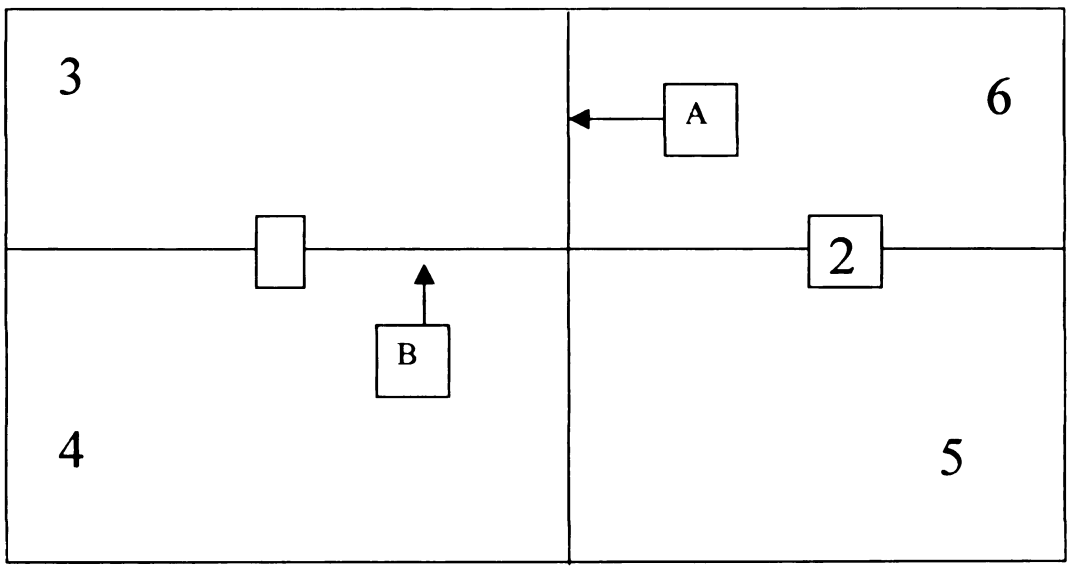
Procedure:

1. Attach your "alleles" to your hat and shirt. Introduce the idea of alleles.
2. Our classroom today will represent a cell. To begin with our cell will be the largest square. This may seem kind of large, but remember, a cell must grow large enough before it divides.
3. First, one person with each type of letter (including upper and lower case) is going to be involved. Come to the middle part of our cell, not lined up yet. The rest of you will be working in a second.
4. Before cells divide, what must happen? **DNA replicates.**
5. In order to show replication of DNA, we are going to link arms with our replicate. Those of you on the outside, find your replicate and link arms.
6. Once they are replicated, what do we call each replicated chromosome? **Sister chromatids**
7. The first division in meiosis is the separation of homologous chromosomes. So homologous pairs need to line up together on the equatorial plane of the cell (line A). Be careful how you are lined up!
8. Divide!!! Area 1 and area 2 represent separate cells (either side of line A). Is this the only way you can arrange yourselves?
9. **Who can tell me which part of what we did represented segregation? Law of independent assortment?**
10. **Are these gametes ready to be fertilized?**
11. The second division needs to occur. Sister chromatids line up along the equatorial plane of cells 1 and 2 (line B)
12. Divide!!! Areas 3-6 represent the four separate cells (separated by lines A and B). **Segregation? Law of independent assortment?**
13. Let's take a look at the alleles found in each "cell." Fill in the chart on the board.
14. Let's do this a few more times. Each time, I am going to give you less and less help remembering what to do. Remember, you do not have to go the

same way each time. We will fill in our gamete information each time on the board.

15. We will choose one gamete from each round to fertilize a gamete that I give you. You will use this information to draw 3 "people."

Classroom Set Up



# students	# homologous Pairs	# of correction enzymes	# students	# homologous pairs	# of correction enzymes
32	8	0	26	6	2
31	7	3	25	6	1
30	7	2	24	6	0
29	7	1	23	5	3
28	7	0	22	5	2
27	6	3	21	5	1

Letter Pairs	32 students	28-31 student	24-27	20-23
A	I	H	G	F
B	L	I	H	G
C	K	J	I	H
D	J	K	J	I
E	M	L	K	J
F	N	M	L	
G	O	N		
H	P			

Name: _____ Hour: _____

Students As Human Chromosomes Activity

Results

Round	Cell 3	Cell 4	Cell 5	Cell 6
1				
2				
3				

	Dominant	Recessive		Dominant	Recessive
A/a	Tongue roller	Can't roll tongue	**I/i**	Brown hair	Non-brown
B/b	Non-blue eyes	Blue eyes	**J/j**	PTC taster	Non-PTC taster
C/c	Widow's peak Hairline	No widow's peak	**K/k**	Polydactly	Five fingers/toes
D/d	Cross right thumb over left	Cross left thumb over right	**L/l**	Myopia (nearsighted)	20/20 vision
E/e	Middigital hair	No middigital hair	**M/m**		
F/f	Curly/wavy hair	Straight hair	**N/n**		
G/g	Attached earlobes	Non-attached earlobes	**O/o**		
H/h	Dimple in chin	No dimple in chin	**P/p**		

Other parent's genotype: _____

Directions:

1. Draw and label a picture of each of the "children" that result from the cross of the "chosen" gamete created during each round of our game and our parent.
2. Answer the analysis questions.

Round One	**Round Two**	**Round Three**

Challenge Questions:

1. Briefly describe what occurs during the process of meiosis. Use the homologous chromosomes **A a** and **T t** to help you explain.

2. Compare the law of segregation with the law of independent assortment.

3. How is it possible that two siblings could have the same parents but look different from each other?

Name: _____ Hour: _____
Partner: _____

Spot the Cat?

Bert and Ernie missed their friend Graycie. For just a brief time, she had touched both of their lives. Even Bert missed her a little from time to time. They decided to visit the Diamonds and PUURRLS cattery one afternoon to see her. Once there, they met some new friends, Bub and his sister, Spot.

Bub was lounging with his big white belly showing. Bert and Ernie noticed that more than half of Bub was made up of white spots. Perched on a counter nearby, they saw Spot. "What a clever name," said Ernie. "She's about half made up of white spots." Bert wondered what made a cat have spotted white fur.

"Last time we were here, we found out that having solid white fur was a dominant trait," he said. "Do you remember Marshmallow and Cloud?"

"Of course I do," replied Ernie. "But they didn't have any spots, Bert. Having spots must be a different type of gene."

"Maybe the amount of spotting is controlled by this other gene. You know, Ernie, we've been getting pretty good at genetics," Bert said proudly. "I'll bet that we could figure out the genotypes and phenotypes of Bub and Spot."

"Won't we need to know what their parents look like?" asked Ernie.

"Naw, Ern. I'll bet we can even figure out what their parents might look like just by using what we know about Bub and Spot. In fact," he continued, "I'll bet we can figure out what the kittens would look like if Bub and Spot were bred together."

Can you do the same? (Concentrate on the spotting trait) Be sure to use your research materials and text book to help you.

A "Tail" of Two Kitties

Sometimes, a client of the Diamond and PUURRLS cattery has a specific cat in mind...a cat that doesn't even exist. They may see some of the parent cats at the cattery in online pictures and think, "I would love a kitten that looks exactly like that!" Such was the case when a very particular client called the cattery and explained that she would love to take home a cat that looked like their award wining Kat. Kat's parents were no longer available for breeding, so the breeders needed to use the cats that were available at the cattery. A cat named Whiskers was chosen and bred with a cat named Scout. Two of the kittens, Calli and Sundae were tortoise cats like Whiskers. The client bought both of them because they looked so much like Kat. One kitten was a cute white cat with spot named Sprinkles. Two of the cats, Garfield and Sherbert, were orange.

"Oh, I love the little orange ones. They are so precious," said the client. "I would take one of them, too, but they are both boys. Since Calli and Sundae are girls, I don't think it would be a good idea. Do you have any kittens available that are orange girls?"

"Actually, most orange cats are boys," said the breeder. "It is very rare to find a female orange cat."

"How strange," said the client. "I thought all cats could be all colors."

"Well, orange pigmentation is an unusual gene," said the breeder. "In fact, tortie cats are always girls."

"I think I may know why!" said the client.

Can you figure out why?

Goals for this PBL:

1. Research how orange pigmentation is passed on.
2. Determine the genotypes of Whiskers, Calli, Sundae, Garfield, and Sherbert.
3. Determine why only female cats appear as torties.
4. Determine why most orange cats are males.
5. Explain whether or not a female cat could be orange.

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