Gummi Bear Genetics: An Exercise in Understanding Epistasis

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Biography

Susan A. Moore obtained her B.S. from Pennsylvania State University and her M.S. and Ph.D. from the University of Michigan. She is currently an Assistant Professor in the Biological Science Department at Duquesne University, where she teaches a General Biology class for majors, an introductory biology course for non-majors, genetics, and immunology. Her research concerns teaching and learning in the large classroom.

Introduction

Many students come into the sophomore level genetics class with little of no understanding of statistics and with little comprehension of how to analyze data. This exercise is designed to introduce epistasis as an extension of the Mendelian dihybrid cross and to analyze data utilizing chi square analysis.

In studying epistasis, it is difficult for students to make a connection with squash and snail colors, or weird weeds, or canine coat colors. Building upon the work of William Baker and Cynthia Thomas called "*Gummy Bear Genetics"* (1998), the introduction of the delicious new species—*Ursa gummi* to the genetics paradigm, makes learning genetics fun and encourages active learning. If a student is not actively engaged in learning in the classroom, the student reverts to memorization to get by. In genetics, that typically means memorizing genotypic and phenotypic ratios and even the steps in how a particular genetic problem is solved. The gummi bear candy appeal to a student's sweet tooth but also adds a bit of whimsy and because gummi bears come in so many different colors, the candy lends itself to genetics. These gummi bear exercises connect scientific method, data analysis, mathematics and biology together all in one delicious package. This is a favorite exercise with my students.

Student Outline

What is Epistasis?

Mendel's study of the dihybrid cross resulted in the predicted phenotypic ratio of 9:3:3:1, where the '9' represents double dominant phenotype (A_B_), the '3's' represents one dominant and one recessive phenotypes (A_bb and aaB_), and the '1' represents both recessive phenotypes (aabb). The genes that Mendel studied did not affect each other. In epistasis, one gene interferes with the expression of a different gene. What results is a change in the phenotypic ratios in the dihybrid offspring. This exercise examines the epistatic relationships of duplicate dominant, duplicate recessive, dominant, and recessive epistasis, that result in changes to the typical Mendelian dihybrid ratios. To predict these changes, you will explore actual epistatic genes in various species and simulated genes in the created model species of *Ursa gummi*.

Exercise 1: Predicting Phenotypes in Epistasis

Your fame as a geneticist has reached the ears of the president. He has asked you take on the task of breeding an *Ursa gummi* army. These delectable soldiers need to have specific characteristics to be good soldiers and you must determine how these traits are inherited and be able to make predictions of potential offspring.

Table 1: Punnett Square Showing Dihybrid Cross

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	Aabb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

Duplicate Dominant Epistasis

Your first assignment is to predict the phenotypic ratios that accompany two genes that code for the same phenotype. This is called Duplicate Dominant Epistasis. Most genetic texts use Shepherds purse (*Bursa bursa-pastoris*) as an example of duplicate dominant epistasis. This weed has two genes that code for the shape of the seed capsule with the dominant allele in both genes coding for triangular shape seed pod. Plants that are homozygous recessive for both genes have seed capsules that are slender or ovoid in shape (Snustad, 2006).

In *Ursa gummi*, two different genes control the same trait with dominant alleles coding for susceptibility to melt at relatively low temperatures. The recessive alleles code for resistance to melting. It is important that *Ursa gummi* soldiers do not melt in the heat of battle. Below are the genotypes and phenotypes representing these traits.

A_ codes for melting	**aa** codes for melting resistance
B_ codes for melting	**bb** codes for melting resistance

1. Using the Punnett square of a dihybrid cross in Table 1, determine what the phenotypic ratio of a cross between melting *Ursa gummi* who have a family history rigidity. (Hint: This means that the parents are heterozygous AaBb)

Duplicate Recessive Epistasis

Most genetics textbooks introduce Duplicate Recessive Epistasis using snails as an example. In snails with albinism, a recessive allele blocks the formation of the necessary compound that a second enzyme uses to make a pigment. Pigmented snails have dominant alleles present at both loci. Recessive alleles of both enzyme blocks production of pigment resulting in albinism (Pierce, 2005).

In *Ursa gummi***,** the final product that is sought is heroic behavior. To become heroic, an *Ursa gummi* must be educated and trained (dominant allele), though an *Ursa gummi* that is going to college is indistinguishable from an uneducated (recessive allele) *Ursa gummi*. Furthermore, one can not have heroic *Ursa gummi* from uneducated Ursa *gummi*. The second step to becoming heroic is to be brave and use the education and apply it to operate complicated equipment, such as a motorcycle, and to ride off into battle. Heroic *Ursa gummi* make good soldiers. Below are the genotypes and phenotypes representing these traits.

A_ codes for educated	**aa** codes for uneducated
B_ codes for bravery	**bb** codes for cowardice

2. Using Table 1, predict the phenotypic ratio of the cross between two heroic *Ursa gummi* that have a family history of cowardice and educated and uneducated members (AaBb).

Dominant Epistasis

In squash, color of fruit is the result of a multi-step metabolic pathway. In the first step, the dominant allele at the locus inhibits the production of pigment changing the expected ratio. Plants that have the dominant allele are white, while plants that are homozygous for the recessive allele, will produce green colored fruit. A second locus codes for a second pigment that uses the green pigment produced by the first loci. Plants with the dominant allele at this second locus, produce a yellow pigment, while plants that are homozygous recessive, do not produce pigment and remain green (Pierce, 2005 and Snustad, 2006).

In *Ursa gummi*, a single dominant allele inhibits the ability to hold and use a spear. The nonviolent *Ursa gummi*, holds a balloon instead. Of course an *Ursa gummi* who can hold a spear would make a good soldier, but it is important to monitor and control any violent behavior of the *Ursa gummi* may exhibit. Below are the genotypes and phenotypes representing these traits.

A_ Balloon holding	**aa** Spear holding
B_ Ceremonial use of spear	**bb** Violent use of spear

3. Using the Punnett square of a dihybrid cross, determine what the phenotypic ratio of a cross between non-violent, balloon holding *Ursa gummi* who have had a family history of spear holding and violence. (AaBb)

Recessive Epistasis

In Labrador retrievers, coat color can be masked by the recessive allele of a gene for pigment deposition and the dog would be a Golden Labrador regardless of the pigment alleles present. A second gene codes for color with the dominant allele for black pigment and the recessive allele for brown or chocolate pigment (Pierce, 2005).

In *Ursa gummi*, the recessive allele for "all work" behavior masks the types of play that *Ursa gummi* enjoy—a dominant allele for "play nice" behavior and a recessive allele for "play rough" behavior. For your *Ursa gummi* soldier, you want an *Ursa gummi* that plays rough. Below are the genotypes and phenotypes representing these traits.

A_ codes for play	**aa** codes for "all work" behavior
B_ codes for "play nice"	**bb** codes for "play rough"

4. Using the Punnett square of a dihybrid cross, determine what the phenotypic ratio of a cross between Nice playing *Ursa gummi* who have had a family history hard working *Ursa gummi* and *Ursa gummi* who played rough. (AaBb)

Exercise 2: Analyzing the Offspring

You have been given a bag of *Ursa gummi* that were derived from a dihybrid cross. Unfortunately, the laboratory notes of the cross were lost. You need to develop a hypothesis regarding the relationship between genotype and phenotype.

1. What are the phenotypic ratios present in your offspring? Use Table 2 to record your observations.

2. Describe the possible interaction between the two genes that would explain the above phenotypic ratios.

Table 2: Data Table of Dihybrid Offspring

Characteristic	Number of *Ursa gummi*
Total	

When determining the phenotypic ratios, calculate them in terms of 16. Remember that the dihybrid ratios are built upon Mendel's ratio of 9:3:3:1 which can be expressed as fractions (9/16, 3/16, 3/16, and 1/16).

Chi Square Analysis

We will now test your hypothesis and determine whether the data you collected support or do not support your hypotheses. Geneticists typically use the chi-square statistical test to determine whether experimentally obtained data are satisfactory approximation of the expected data. In short, this test expresses the difference between expected (hypothetical) and observed (collected) numbers as a single value, chi2. If the difference between observed and expected results is large, a large chi2 results and it is time to seek a new hypothesis to explain the data, while a small difference results in a small chi2—hey hypothesis is supported. Chi2 values are calculated according to the formula:

$$(\text{Observed Value} - \text{Expected Value})^2 \div (\text{Expected Value})$$

In addition, we must establish degrees of freedom. The degrees of freedom represent the number of ways the observed categories or phenotypes can vary. It is always one less than the number of categories (n) of possible outcomes ($n - 1$).

Note: We use the "raw numbers" of the data and compare it to the "raw numbers" we expected. We do not use probability or ratios or fractions in chi2. You will need to convert your hypothesis of predicted ratios to the numbers of *Ursa gummi*. Multiply your predicted ratio by the total number of *Ursa gummi* in your bag to obtain your expected values.

3. Calculate the chi2 value that compares your data with your hypothesis. Use Table 3.

4. Does your data support or falsify your hypothesis?

Table 3: Chi2 Analysis of Dihybrid Offspring

Characteristic	Observed	Expected	$(\text{Obs} - \text{Exp})^2 \div \text{Exp}$
Total			
degrees of freedom			

Notes for Instructor

Students are encouraged to use their imagination in describing the genotypes and phenotypes of their own offspring, however, they can use the examples from the problems they have already worked. This exercise strengthens the link between biology and statistics and makes the problem solving aspect of genetics a tasty treat.

In the first exercise, print multiple copies of Table 1. Students can use this Punnett square as a worksheet for the different examples of epistasis. It helps to have colored pencils on hand, for the students to color code the different phenotypes that are present.

For the second exercise, Table 4 gives suggested numbers of colored gummis for the bags of *Ursa gummi* offspring. When sorting the gummi bear candies by color, keep it clean, because you know the students are going to eat their offspring. Keeping the totals of candies a bit over 30 supplies enough sugar for students working in three's.

These exercises connect scientific method, data analysis, mathematics and biology together all in one delicious package. This is a favorite exercise with my students. They have fun while they are learning and that is a double win for the instructor. Yes, the *Ursa gummi* bears may be a bit whimsical and the analogies are a bit of a stretch for use in a genetics classroom, but the students truly get involved. When the traditional examples are juxtaposed with the *Ursa gummi* examples, students can make the connections. When students make their own hypothesis and explanations regarding the inheritance patterns in their bag of *Ursa gummi* offspring, the students are critically thinking.

Table 4: Suggested Ratios of Gummi Bear Candies

Gene Interaction	Phenotypic Ratio	Suggested Offspring
Dominant Epistasis	12:3:1	25 clear 7 green 1 orange
Duplicated Recessive Epistasis	9:7	19 orange 13 red
Duplicated Dominant Epistasis	15:1	29 pink 2 green
Recessive Epistasis	9:3:4	19 green 6 clear 9 yellow

References Cited

Pierce, Benjamin A. 2005. Genetics: A Conceptual Approach (Second Edition). W. H. Freeman. New York, New York. 720 pages.

Snustad, D. P., and M. J. Simmons. 2006. Principles of Genetics (Fourth Edition). JohnWiley and Sons. Hoboken, New Jersey. 866 pages.

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In studying epistasis, it is difficult for students to make a connection with squash and snail colors, or weird weeds, or canine coat colors. Building upon the work of William Baker and Cynthia Thomas and their article in The Science Teacher called "*Gummi Bear Genetics*", the introduction of the delicious new species—*Ursa gummi* to the genetics paradigm, made learning genetics fun and encouraged active learning. The gummi bear appeals to the students sweet tooth but also adds a bit of whimsy and because gummis come in so many different colors, the candy lends itself to genetics. These gummi bear exercises connect scientific method, data analysis, mathematics and biology together all in one delicious package. This is a favorite exercise with my students.

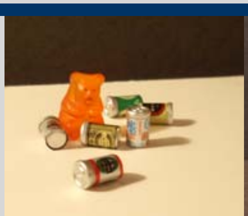
The first activity involves solving problems students are informed that they are trying to breed a gummi bear army. These delectable soldiers need to have specific characteristics to be good soldiers and the students must understand how these traits are inherited Using various fabricated dihybrid crosses, the concepts of how 2 genes can be inherited independently but how one gene can affect the phenotypic expression ratio. Students must work through the examples and determine the phenotypic ratios of offspring.

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

Punnett square: A punnett square demonstrating the predicted 9:3:3:1 phenotypic results of dihybrid cross. 9 A_ B_ (red) : 3 A_ bb (white) : 3 aa B_ (blue): 1 aa bb (yellow)

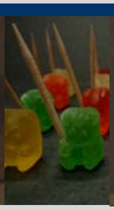
Duplicate Dominant Epistasis: In Shepherds purse, two genes code for seed shape with dominant allele in both genes coding for triangular shape seed. Recessive alleles for both genes, codes for a slender seed container. In *Ursa gummi*, two genes code for susceptibility to melt at relatively low temperatures. The recessive alleles code for resistance to melting. Punnett square reveals a 15:1 phenotypic ratio of melting to non melting status.

A _ codes for melting — aa codes for melting resistance
B _ codes for melting — bb codes for melting resistance




Duplicate Recessive Epistasis: In snails, a recessive allele blocks the formation of the necessary compound that a second enzyme uses to make a pigment. Recessive alleles of both enzyme blocks production of pigment. In *Ursa gummi,* the final product that is sought is heroic behavior. To become heroic, a gummi must be educated, though an educated gummi is indistinguishable from an uneducated gummi when young. The second step to becoming heroic, is to be brave and use the education and apply it to operate complicated equipment. Punnett square reveals 9 heroic : 7 nonheroic.

A_ codes for educated — aa codes for uneducated
B_ codes for bravery — bb codes for cowardice


Dominant Epistasis: In squash, a single dominant allele at the W locus inhibits the production of pigment. In *Ursa gummi*, a single dominant allele inhibits the ability to hold and use a spear. The nonviolent gummi, holds a balloon instead. Punnett square reveals 12 balloon holding : 3 ceremonial spear holders : 1 violent use of spears

A_ Balloon holding — aa Spear holding
B_ Ceremonial use — bb Violent use



Recessive Epistasis: In Labrador retrievers, coat color can be masked by recessive allele of a gene for pigment deposition and the dog would be a Golden Labrador. A second gene codes for color with the dominant allele for black pigment and the recessive allele for brown or chocolate pigment. In *Ursa gummi*, the recessive allele for "all work" behavior masks the types of play that gummis enjoy—a dominant allele for "play nice" behavior and a recessive allele for "play rough" behavior.

A_ codes for play
aa codes for "all work" behavior
B_ codes for "play nice"
bb codes for "play rough"

	AB	Ab	aB	ab
AB	AABB	AABb	AaBB	AaBb
Ab	AABb	AAbb	AaBb	Aabb
aB	AaBB	AaBb	aaBB	aaBb
ab	AaBb	Aabb	aaBb	aabb

Recessive epistasis Punnett square reveals the 9 plays nice gummi : 4 all work gummis : 3 plays rough gummi

Students are then given the offspring of a dihybrid cross and are asked to develop a hypothesis regarding the relationship between genotype and phenotype utilizing what they already know from the problems and to test their hypothesis by chi square analysis. Students are encouraged to use their imagination in describing the genotypes and phenotypes of their own offspring, however, they can use the examples from the problems they have already worked. This exercise strengthens the link between biology and statistics and makes the problem solving aspect of genetics a tasty treat.

Gene Interaction	Phenotypic Ratio	Suggested Offspring
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Recessive Epistasis	9 : 3 : 4	19 green 6 clear 9 yellow

Table gives suggested amounts of gummis for second exercise.

Conclusion

These gummi bear exercises connect scientific method, data analysis, mathematics and biology together all in one delicious package. This is a favorite exercise with my students. Students having fun while learning is a double win. Yes, the gummi bears may be a bit whimsical and the analogies used a bit of a stretch for use in a genetics classroom, but the student truly get involved. When the traditional examples are juxtaposed with the gummi examples, students can make the connections. When students make their own hypothesis and explanations regarding the inheritance patterns in their bag of gummi offspring, the pieces fall together. The gummi bear appeals to the students sweet tooth but also adds a bit of whimsy and because gummis come in so many different colors, the candy lends itself to genetics.

Bibliography

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