Gene Squares

61

2–3
40- to 50-minute sessions

ACTIVITY OVERVIEW

PROBLEM SOLVING

SUMMARY

Students use Punnett squares to predict the approximate frequencies of traits among the offspring of specific critter crosses.

KEY CONCEPTS AND PROCESS SKILLS

1. An allele is one of the two or more forms of a gene present in a population.
2. Genetic crosses can be analyzed by using a standardized means of representation called a Punnett square, when each parent's alleles for a trait are known.
3. A Punnett square is a visual representation of the relative probabilities of offspring outcomes, for both gene combinations and visible traits.

KEY VOCABULARY

allele

carrier

dominant

homozygous

heterozygous

Punnett square

recessive

MATERIALS AND ADVANCE PREPARATION

For each student

1 Student Sheet 61.1, "Punnett Squares—Step by Step"

* 1 blue pencil (optional)

* 1 orange pencil (optional)

**Not supplied in kit*

TEACHING SUMMARY

Getting Started

1. Revisit the coin-tossing results from Activity 59, "Gene Combo."

Doing the Activity

2. Students read and learn how to use a Punnett square.
3. Students do additional practice on Student Sheet 61.1, "Punnett Squares—Step by Step."

Follow–Up

4. The class discusses the usefulness of Punnett squares in helping them to organize predictions of genetic crosses.

BACKGROUND INFORMATION

Punnett Squares

A Punnett square is a tool for doing probability calculations; its structure represents sexual reproduction. When the single alleles that each parent can contribute are written along the top and side of the table (see Figure 1 on page D-41 in the Student Book), the formation of sex cells is implied. When one allele from each parent is transferred to a box within the table (see Figure 2 on page D-42 in the Student Book), fertilization is represented—the union of genes contributed by egg and sperm. While Punnett squares are not strictly necessary for solving genetics problems (see section below), they help students visualize genetic crosses. They are also useful in analyzing the outcomes of more complex crosses involving multiple traits, but this is typically covered in high school biology.

Mendel's Probability Calculations

Mendel's data enabled him to recognize that the essence of inheritance is probability, since alleles are inherited randomly during sexual reproduction. Punnett squares organize and display the mathematics behind the inheritance of a trait that follows Mendelian behavior.

For example, consider Problem 1 (the Ocean/Lucy cross) on Student Sheet 61.1, "Punnett Squares—Step by Step." This cross is analogous to the classic Mendelian Generation Two cross, as well as to the flowering-tobacco breeding that produced the green and yellow seedlings your students germinated. The Punnett square provides a visual representation of the "multiplication rule" for probabilities. In this case, the rule states that the probability of producing an orange-tailed offspring (tt) equals the probability of getting an orange-tail allele (t) from the father multiplied by the probability of getting another orange-tail allele (t) from the mother. That is,

probability of an offspring having an orange tail =

probability of (tt) = (probability of t from father) x (probability of t from mother) = (1/2) x (1/2) = 1/4

(This calculation is the reciprocal of the calculation of the total number of boxes in the Punnett square. That is, the total number of boxes = 2 x 2 = 4.)

Since the probability of having an orange tail is 1/4, the probability of having a blue tail must be 1- 1/4 = 3/4. The explicit calculation of this is more complex than for orange tail, since there is more than one way to inherit a blue tail:

probability of homozygous offspring TT = (1/2) x (1/2) = 1⁄4
probability of heterozygous offspring Tt = 2 x (1/2) x (1/2) =
2 x 1/4 = 1/2

(Note that there are two ways for the offspring to be heterozygous: either T from the father and t from the mother, or T from the mother and t from the father. In Activity 59, "Gene Combo," these two ways were notated as Tt and tT.)

The probability of an offspring having a blue tail (TT or Tt) is the sum of the two probabilities: 1/2 + 1/4 = 3/4

Note that the understanding of Punnett squares should be the focus here, not the use of vocabulary. However, the terms *homozygous* and *heterozygous* may help students assign meaning to the Punnett squares.

Odds vs. Probabilities

As was addressed in Activity 59, a 3:1 ratio is exactly equivalent to the pair of fractions 3/4 and 1/4. In the ratio "3:1," a *part* of the whole is compared to *another part* of the whole—hence, (3 blue-tailed):(1 orange-tailed). A ratio is often written x:y, but can also be written x/y (a fraction *is* a ratio). In contrast, a true fraction compares a *part* to the *whole*—hence, 3⁄4 of a large set of offspring critters are blue-tailed and 1/4 are orange-tailed.

Students often confuse these two notations, for example writing "4:1" when they mean 3:1, or "2:1" when they mean 1:1. Such confusion can obscure an otherwise sound understanding and make classroom communication difficult, so it is a good idea to address this directly.

TEACHING SUGGESTIONS

■ GETTING STARTED

1. **Revisit the coin-tossing results from Activity 59, "Gene Combo."**

Review with students the outcomes of the breeding experiment between Ocean and Lucy, as simulated in Activity 59. Ask for a volunteer to come to the board and explain the frequency of each tail color. Ask, ***Why do about 1/4 of the offspring have orange tails?*** Do not be concerned if no student can yet provide a clear, concise explanation.

Have students read the Introduction and Challenge on page D-39 in the Student Book. State that a Punnett square is a standard way of displaying the predicted outcomes of a genetic cross. Have students begin working through the interactive reading in the Procedure. These passages explain how to set up, complete, and interpret a Punnett square, using the tail colors produced by the Skye/Poppy cross as a simple example. (Students will work through the Lucy/Ocean cross and two more examples on Student Sheet 61.1, "Punnett Squares—Step by Step.")

■ **Teacher's Note**: You may wish to have students complete the reading as individuals or aloud in groups of four. Alternatively, you can use the material as a guide to present how to complete a Punnett square.

■ DOING THE ACTIVITY

2. **Students read and learn how to use a Punnett square.**

Be prepared to help students understand why Skye is assumed to be "TT" for tail-color alleles, and Poppy "tt." The critter breeding experiments confirmed this assumption, since it was demonstrated that orange tail color is recessive and that Skye was homozygous for blue tail. By constructing Punnett squares, students are showing how those results could have been predicted. (Although the critter-breeding experiments are imaginary, Mendel's results using several different pea plant traits were exactly parallel. In addition, students themselves are about to obtain a 3:1 ratio among their flowering tobacco seedlings.)

In constructing a Punnett square, the step that usually causes the most difficulty is the placement of parental alleles around the table. One parent's alleles are split apart along the top row, while the other's are divided along the side column (this represents the formation of sex cells). Be sure to stress that it doesn't matter which parent is on the top and which is along the side. The boxes in the square are filled in with the alleles from the appropriate intersecting column and row, as shown in Figure 2 on page D-42 in the Student Book (this represents fertilization).

■ **Teacher's Note**: Be alert for the need to clarify the term *allele*. There are two different forms, or alleles, of the critter tail-color gene: one, represented here as "T," is associated with the dominant trait of blue tail; the other, represented as "t," is responsible for the recessive trait of orange tail. A single gene determines critter tail color, but each critter has two alleles of that gene—which may be the same (homozygous) or different (heterozygous).

The second most challenging step in using Punnett squares is interpreting the results. The four boxes of a 2 x 2 square do **not** indicate the results for any four particular offspring. Instead, each box represents a

1/4 probability for any one offspring. In the cross of Skye and Poppy, every box contains Tt, so the chance of one of their offspring being a heterozygous blue-tailed critter is 4 times 1/4, or 1 (100%). Remind students that in Activity 59, "Gene Combo," they modeled the randomness of genetic crosses by tossing coins.

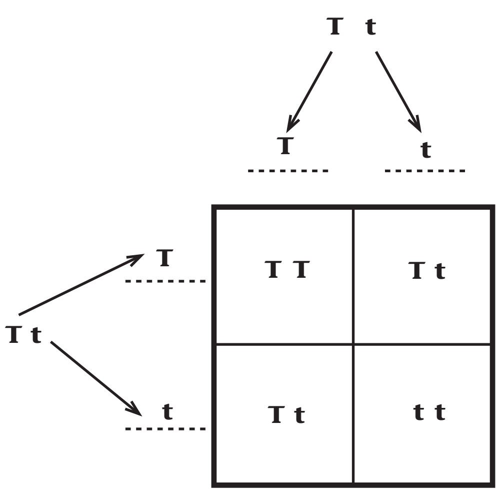
The reading also introduces the term *carrier* as a concept in genetics: an individual heterozygous for a recessive genetic condition (usually a heredity disease, but it can be any recessive trait) carries an allele for that condition but does not show the trait. Note that Analysis Questions 3 and 4 provide further experience working with genetic carriers.

3. Students do additional practice on Student Sheet 61.1, "Punnett Squares—Step by Step."

Student Sheet 61.1 provides students with additional guided practice. Note that grids for the squares are provided. These problems may be done in class by students working individually, or they may be assigned as homework.

Problem 1 includes hints for how to place the parents' alleles around the square and includes a reprinting of Figure 2 from the Student Book. Assist students as needed. The expected answers are as follows:

Problem 1

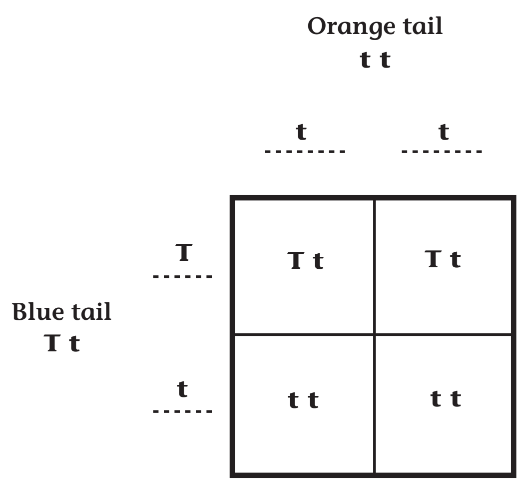


3/4 blue

1/4 orange

Note that about 1/4 of the offspring are homozygous for blue tail color (TT), and about 1/2 are heterozygous for blue tail color (Tt).

Problem 2



1/2 blue

1/2 orange

Note that all of the blue-tailed offspring are heterozygous (Tt).

Problem 3

Blue tail
T T

Blue tail
T t

	T	T
T	T T	T T
t	T t	T t

all blue

Note that about 1/2 of the offspring are homozygous for blue tail color (TT), and about 1/2 are heterozygous for blue tail color (Tt).

When you observe that most or all of the students have mastered how to set up and complete the squares, move on to the Analysis Questions.

■ FOLLOW–UP

4. The class discusses the usefulness of Punnett squares in helping them to organize predictions of genetic crosses.

Discuss the advantages of using a standard format for solving genetics problems: this organizes one's work and makes it easier to compare results with others. Analysis Question 1 revisits the beginning of this activity where students were asked to explain the results of "Gene Combo" in words. Punnett squares provide a visual representation for probable results.

Tell students that soon they will apply this kind of reasoning to human genetics. Though breeding experiments may not be performed with humans, predicting the possible offspring of two individuals can be very important (students may recall some discussion of this in the film they watched in Activity 56, "Joe's Dilemma").

Analysis Question 2 encourages students to make their own choices in how to represent alleles of a gene. There is no one correct way to do this; the solutions in the *Suggested Answers* present rationales for the two most common ways used in introductory genetics.

Questions 3 and 4 address the concept of carrier in biology. The concept of genetic carrier often appears in the media in connection with hereditary conditions and genetic counseling.

Finally, emphasize that, despite their misleading appearance, Punnett squares do not indicate specific mating results. Genes are not used up as organisms reproduce, so perfect offspring ratios are not to be expected—although the larger the sample size of offspring, the closer the experimental ratio is likely to be. Refer again to the coin-tossing data (Activity 59, "Gene Combo"), students' seedling results (if gathered already), and Mendel's data.

SUGGESTED ANSWERS TO ANALYSIS QUESTIONS

1. *Compare the results of your Punnett square for Problem 1 on Student Sheet 61.1 with the results of the Ocean/Lucy cross in Activity 59, "Gene Combo." Why are they similar?*

   The Punnett square allows an easy calculation of the likelihood of each allele combination and trait in the offspring. In "Gene Combo," random coin tosses were used to model the 1/2 chance of each parental allele being given to an offspring.

Students may notice that in a sense there is no difference: the cross is the same and the results are the same. However, in this activity students have used a Punnett square to display theoretical results, whereas Activity 59 was a simulation of real experimental results, which do not perfectly match theoretical predictions.

2. *Refer to the table of Mendel's results in Activity 60, "Mendel, First Geneticist," on page D-36.*

   a. *What are the traits for pea flower color? Suggest letters you might use to represent the alleles for flower color.*

   Flower color is either purple or white. Since purple is dominant to white, the alleles could be represented as either F = purple and f = white, or P = purple and p = white. (F/f are short for flower color, the description of the characteristic. P/p are short for purple, the dominant trait.)

   b. *What are the traits for seed surface? Suggest letters you might use to represent the alleles for seed surface.*

   Seed surface is either wrinkled or smooth. Since smooth is dominant to wrinkled, the alleles could be represented as S = smooth and s = wrinkled. (S/s could be short for either seed surface, the characteristic in general, or smooth, the dominant trait.)

3. *Review your results on Student Sheet 61.1. Why is it impossible for offspring to show the recessive trait if one parent is homozygous for the dominant trait?*

   The parent homozygous for the dominant trait cannot contribute a recessive allele to any offspring (barring, of course, an unlikely random mutation). As long as an allele for the dominant trait is present, the offspring will display the dominant trait. Offspring may be carriers of the recessive allele, but none will display the recessive trait.

4. *A scientist has some purple-flowered pea plants. She wants to find out if the pea plants are homozygous for the purple flower color.*

   a. *What cross will be best to find out if the purple-flowered peas are homozygous?*

   Cross them with white-flowered plants, so that the white allele, if present, will reveal itself. This kind of breeding test, against a second parent showing the recessive trait, is called a test cross.

   b. *Use Punnett squares to show what will happen if the plants are crossed with white-flowered plants and*

      i. *the purple-flowered plants do not have an allele for the white trait.*

	F	F
f	Ff	Ff
f	Ff	Ff

   There will be no white-flowered offspring, as all offspring will be heterozygous for purple flowers.

ii. *the purple-flowered plants do have an allele for the white trait.*

	F	F
f	Ff	ff
f	Ff	ff

Half the offspring will have white flowers and half will have purple flowers. Because there are white-flowered offspring, the purple-flowered parents must have been carrying a recessive white allele. (About half the offspring will have white flowers if the purple-flowered parent is heterozygous.)

Name ______________________________ Date ____________

Punnett Squares—Step by Step

The cross between the Generation 2 (Tt) critters Ocean and Lucy is:

Ocean x Lucy

Tt x Tt

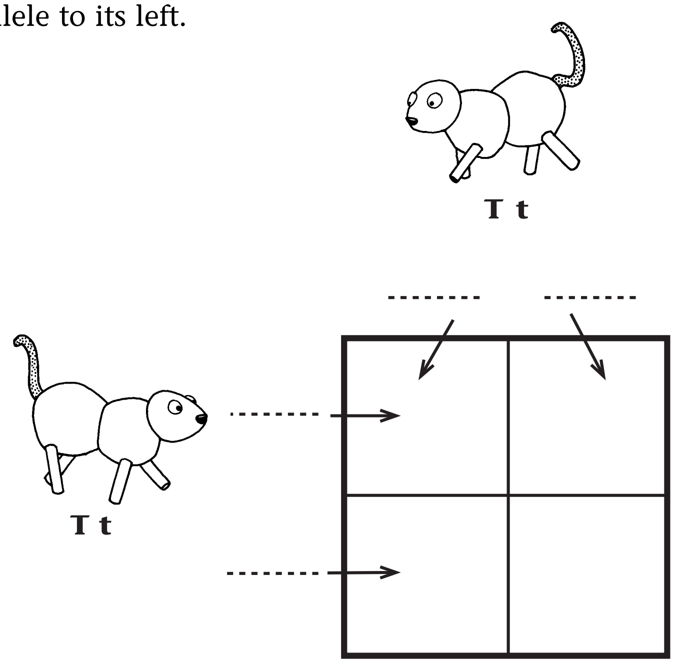
T = allele for blue tail color (dominant)
t = allele for orange tail color (recessive)

Note that while Ocean and Lucy both have blue tails, they are both heterozygous.

1. Referring to the example above from your book, complete this Punnett square for the cross between Ocean and Lucy.

a. Place Ocean's and Lucy's alleles on the dotted lines in the Punnett square.

b. Complete the Punnett square by filling in each box with the allele above it and the allele to its left.



c. Use either a blue pencil or a regular pencil to shade in the squares for offspring that will have blue tails in your Punnett square above.

d. About what **fraction** of the offspring of Ocean and Lucy are predicted to have blue tails, according to the Punnett square?

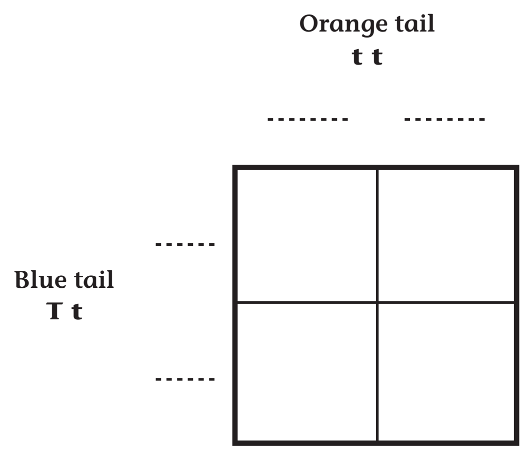
e. About what **fraction** are predicted to have orange tails?

Name ______________________________ Date ____________

Punnett Squares—Step by Step

Generation 3 includes some critters with orange tails and some with blue tails.

2. Complete this Punnett square for a cross between an orange-tailed critter and a heterozygous blue-tailed (Tt) critter.

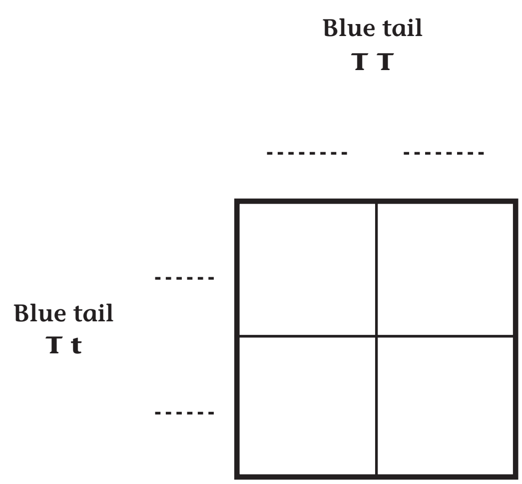


a. Use pencil to shade in the squares for offspring with blue tails.

b. About what **fraction** of the offspring are predicted to have blue tails?

c. About what **fraction** are predicted to have orange tails?

3. Complete this Punnett square for a cross between a heterozygous blue-tailed (TT) critter and a heterozygous blue-tailed (Tt) critter



a. Use pencil to shade in the squares for offspring with blue tails.

b. About what **fraction** of the offspring are predicted to have blue tails?

c. About what **fraction** are predicted to have orange tails?