B4 Punnett Squares

Key Question: *How are Punnett squares used to make predictions about inheritance?*

Students learn how to use Punnett squares to predict the most likely traits of the offspring of the creatures they built. Two groups work together and "mate" the Crazy Creatures that they flipped for in the previous investigation. Students create Punnett squares to determine the most probable phenotype for each trait of the offspring. Students then flip coins to see what genotypes and phenotypes the offspring will actually have. This shows students that even though Punnett squares can be used to predict the outcome, chance still plays a huge role in genetics.

Learning Goals

- ✔ Create Punnett squares to determine the most probable genotype and phenotype for a given cross.
- ✔ Make predictions with Punnett squares and test predictions.
- ✔ Calculate the probability of inheriting a certain genotype and phenotype.

GETTING STARTED

Time 50 minutes

Setup and Materials

1. Make copies of investigation sheets for students.
2. Watch the equipment video.
3. After the investigation, have your students use the organization chart (included in the Crazy Traits set) to make sure they have all of the parts.
4. Review all safety procedures with students.

Materials for each group

- Crazy Traits set

Online Resources

Available at curiosityplace.com

- Equipment Video: Crazy Traits
- Skill and Practice Sheets
- Whiteboard Resources
- Animation: Punnett Square
- Science Content Video: Genotypes and Phenotypes
- Student Reading: Predicting Heredity

Vocabulary

Punnett square – a chart that shows all of the possible combinations of alleles from two parents

NGSS Connection

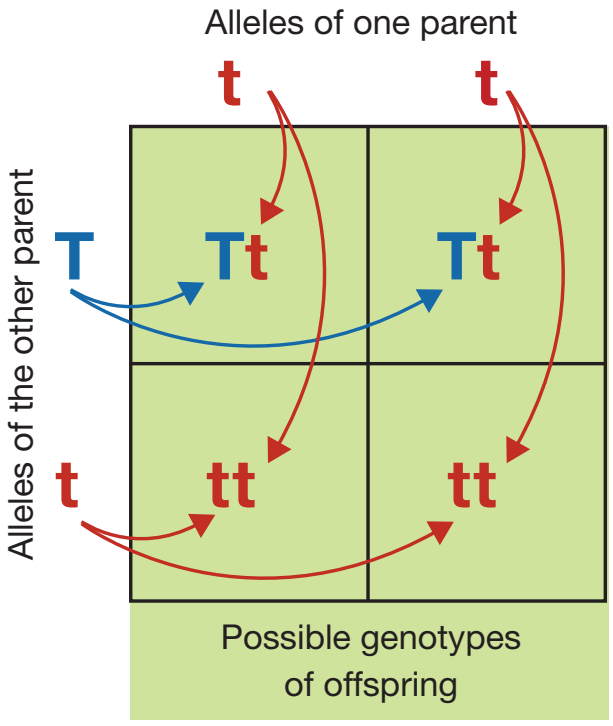
This investigation builds conceptual understanding and skills for the following performance expectation.

HS-LS3-3. *Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.*

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data	LS3.B: Variation of Traits	Scale, Proportion, and Quantity

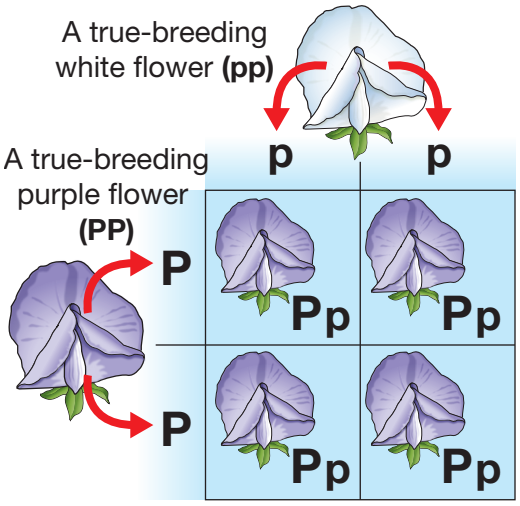
BACKGROUND

You can predict the genotypes and phenotypes of offspring if you know the genotypes of the parents. A **Punnett square** shows all of the possible combinations of alleles from two parents. Each of the four boxes represents one possible genotype that the offspring might have.



You can use a Punnett square to show Mendel's first cross. He crossed a true-breeding, purple-flowered plant with a true-breeding, white-flowered plant. Since the purple-flowered plant is true-breeding, it has two dominant alleles. The genotype of the purple-flowered plant is **PP**. Since white flowers are recessive, the only possible genotype for a white-flowered plant is **pp**.

As you can see, all of the offspring in Mendel's first cross had a genotype of **Pp**. The purple allele was dominant; that's why all of the plants in the first generation had purple flowers. As is shown below, a Punnett square predicted these results. The only possible genotype is **Pp** and the only possible phenotype is purple flowers.



When you flip a coin, there is a 50 percent chance you'll get heads and a 50 percent chance you'll get tails. The way the coin lands is completely random. Like flipping a coin, the chance of inheriting a certain genotype and phenotype is random.

Probability is the mathematical chance that an event will occur. Probability can be expressed as a fraction or a percentage. For example, suppose one out of the four squares in a Punnett square contains **pp**. The probability of any offspring having **pp** is therefore 1/4. To convert this to a percentage, take the numerator of the fraction divided by the denominator and multiply by 100.

$$\frac{1}{4} \times 100 = 25\%$$

Therefore, there is a 25 percent chance of any offspring having the **pp** genotype.

5E LESSON PLAN

Engage

Ask students, "What is the probability that a newborn baby will be a boy or girl?" Students should guess that the chance is 50:50. Here is a way that you can model the determination of sex. Obtain two clear containers. Label one container "MALE" and the other "FEMALE." Use colored beans to represent the sex chromosomes. For instance, you may use black beans to represent male (Y) and white beans for female (X). Place an even number of white beans (at least 10) in the "female" jar. Place the same number of beans in the jar labeled "male," but ensure that half the beans are white and the other half are black. Blindfold or cover the eyes of a student volunteer. Ask the student to choose one bean from each jar. Make a data table on the board to record the data. Return each bean to the jar from which it was taken. Repeat this process 20 times.

At the conclusion, discuss the number of male and female offspring. Was the ratio of males to females 1:1? Also, have students explain the importance of selecting one bean from each jar.

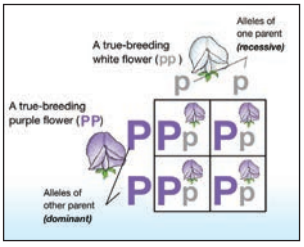
Explore

Complete Investigation B4, *Punnett Squares*. In this investigation, students learn how to use Punnett squares to predict the most likely traits of the offspring of the creatures.

Explain

Revisit the Key Question to give students an opportunity to reflect on their learning experience and verbalize understandings about the science concepts explored in the investigation. Curiosityplace.com resources, including student readings, videos, animations, and whiteboard resources, as well as readings from your current science textbook, are other tools to facilitate student communication about new ideas.

Science Content Video
Genotypes and Phenotypes



Animation
Punnett Square

Elaborate

After the investigation, have students revisit the data from the *Engage* activity. Ask them to create a Punnett square that predicts the probability of offspring being male or female. Remind them that the genotype for a female is XX and a male is XY.

Evaluate

- During the investigation, use the checkpoint ✓ questions as opportunities for ongoing assessment.
- After completing the investigation, have students answer the assessment questions on the *Evaluate* student sheet to check understanding of the concepts presented.

PUNNETT SQUARES

Explore — INVESTIGATION B4

Name _____ Date _____

B4 Punnett Squares

How are Punnett squares used to make predictions about inheritance?

NASA is setting up an educational exhibit to teach people about Crazy Creatures and their planet, Geneticus. NASA has asked you to help them select the initial breeding pair to include in their exhibit. They want to be sure that the parents that they pick and their offspring will represent a variety of all the traits that Crazy Creatures can have. You know that you can predict the genotypes and phenotypes of offspring if you know the genotypes of the parents. A **Punnett square** shows all the possible combinations of alleles from two parents. In this investigation, you will create Punnett squares to help NASA select the best creatures for their new display.

Materials:
✔ Crazy Traits set

1 Using a model to make predictions

Look at this Punnett square showing the parents from the B3 investigation—Tt for all the traits. The two alleles for each of the parents are shown outside the squares—one parent across the top and one parent down the side. Since each parent gives at least one allele to their offspring, the squares represent the four possible combinations of alleles that the offspring could receive.

	T	t
T	TT	Tt
t	Tt	tt

TT = 1/4 = 25%
Tt = 2/4 = 50%
tt = 1/4 = 25%

a. What are the possible genotypes of the offspring?

Possible genotypes: TT, Tt, tt

Probability plays an important role in heredity. Although we can use Punnett squares to show the possible outcomes, the actual chance of inheriting a certain genotype or phenotype is still random. Probability is the mathematical chance that an event will occur. Probability can be expressed as a fraction or a percentage. Since there are four possibilities in Punnett squares, it is easy to make fractions: 1/4, 2/4 or 1/2, 3/4, and 4/4 or 1. To convert these fractions to percentages, take the numerator of the fraction divided by the denominator and multiply by 100, as shown above.

b. What is the probability that the offspring will show the dominant phenotype?

The probability is 3/4, or 75%. (25% TT + 50% Tt)

Explore — INVESTIGATION B4

1. You will predict the probable traits of the offspring of two Crazy Creatures to see if they are suitable candidates for the NASA education exhibit. You will work with another team and use the creatures you created in the last investigation. Your teacher will pair you up with another team that has a creature of the opposite sex.
2. The gender row of Table 1 has been partially filled in for you. Since there is a 50% chance of the offspring being male or female, you will guess what sex you think the offspring will be. Fill in your prediction in the predicted phenotype column.
3. Now, fill in the genotypes for the mother and father for all the other traits in columns 2 and 3 in Table 1.
4. For each trait, make a Punnett square to show the possible combinations of alleles for the offspring.
5. Determine the most probable phenotype by figuring out which percentage of offspring would have each genotype. Then, use Table 2 to determine which phenotype is associated with that genotype. Fill in the most likely phenotype in column 4 of Table 1. In the case of gender, you will find that there is an equal chance of having either phenotype – two would have one trait, while the other two would have the other trait. If this is true, you can guess what gender you think that the offspring will most likely have.
6. Next, write the fraction to show what subset of the offspring would most likely have the predicted phenotype. You can create a fraction by using the number of boxes showing offspring with each genotype divided by four (the total number of squares). Use this fraction to find the percent in step 7.
7. Finally, find the percent of the offspring that would most likely have the predicted phenotype. To calculate a percent, divide the numerator by the denominator and multiply by 100. Record the percent in column 5 of Table 1.
8. Repeat these steps for traits 3 through 14.

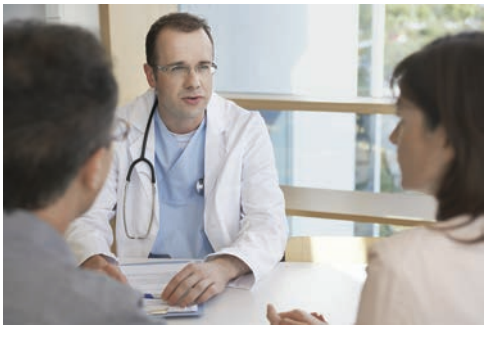
STEM CONNECTION

How are Punnett squares used in medicine?

Cystic fibrosis (CF) is an inherited disease that causes thick, sticky mucus to form in the lungs and other organs. In the lungs, this mucus blocks the airways, causing lung damage and making it hard to breathe. People with CF have a shorter-than-normal life expectancy. The good news is that as treatments for CF improve, the life expectancy for people with the disease is rising. Today many people with the disease live into their 30s, 40s and beyond.

Physicians and genetic counselors often use Punnett squares as predictive tools for parents who are considering having children if a genetic disorder, like cystic fibrosis, is present in their family history.

Imagine a couple who both have a history of cystic fibrosis in their families. Of course, they are worried about whether their children will be healthy or have the disorder.



Explore INVESTIGATION B4

Table 1: Predicted phenotypes and probability

1 Trait	2 Genotype of mother	3 Genotype of father	4 Predicted phenotype	5 % Probability	6 Actual genotype	7 Actual phenotype
1. Sex	XX	XY	male	50%	XY	male
2. Skin color	Tt	Tt	purple	50%	TT	red
3. Leg	TT	tt	short	100%	Tt	short
4. Foot	Tt	TT	webbed	100%	Tt	webbed
5. Arms	tt	Tt	long	50%	tt	short
6. Hands	TT	tt	paws	100%	Tt	paws
7. Eye color	TT	TT	red	100%	TT	red
8. Eyebrows	Tt	Tt	unibrow	75%	TT	unibrow
9. Beak	tt	Tt	crusher	50%	Tt	trumpet
10. Ears	Tt	tt	mouse	50%	tt	mouse
11. Antenna length	Tt	Tt	long	75%	tt	short
12. Antenna shape	Tt	TT	knob	100%	TT	knob
13. Tail	TT	tt	short	100%	Tt	short
14. Wings	TT	tt	no wings	100%	Tt	no wings

Answers will vary. Sample answers above.

Explore INVESTIGATION B4

Table 2: Key to genotypes and phenotypes

Trait	Genotypes and phenotypes
1. Sex	**XX** – female **XY** – male
2. Skin color	**TT** – red **Tt** – purple **tt** – blue
3. Leg	**TT** – short **Tt** – short **tt** – long
4. Foot	**TT** – webbed **Tt** – webbed **tt** – talon
5. Arms	**TT** – long **Tt** – long **tt** – short
6. Hands	**TT** – paws **Tt** – paws **tt** – claws
7. Eye color	**TT** – red **Tt** – one red and one green **tt** – green
8. Eyebrows	**TT** – unibrow **Tt** – unibrow **tt** – separate
9. Beak	**TT** – trumpet **Tt** – trumpet **tt** – crusher
10. Ears	**TT** – elephant **Tt** – elephant **tt** – mouse
11. Antenna length	**TT** – long **Tt** – long **tt** – short
12. Antenna shape	**TT** – knob **Tt** – knob **tt** – star
13. Tail	**TT** – long **Tt** – short **tt** – none
14. Wings	**TT** – no wings **Tt** – no wings **tt** – wings

2 Stop and think

a. What is a Punnett square? What information is needed to create a Punnett square?

A Punnett square shows all the possible combinations of alleles from two parents. You need to know the genotypes of the parents in order to create a Punnett square.

b. What is probability? What does probability have to do with inheritance?

Probability is the mathematical chance that an event will occur. It has to do with inheritance because parents can only pass on one of their two alleles for each trait to their offspring. It is random which allele each parent donates.

STEM CONNECTION

(continued from previous page)

Both parents suspect that they carry the recessive allele for cystic fibrosis. For this example, we can use "A" as being the dominant, normal allele and "a" as the recessive allele that is responsible for cystic fibrosis. Let's assume that both parents are carriers but do not show symptoms of the disorder. So the parents are both heterozygous (Aa). Cystic fibrosis only affects those who are homozygous recessive (aa). The Punnett square below makes it clear that at each birth, there will be a 25% chance of the parents having a normal homozygous (AA) child, a 50% chance of a healthy heterozygous (Aa) carrier child, and a 25% chance of a homozygous recessive (aa) child who will have cystic fibrosis.

If both parents are carriers of the recessive allele for a disorder (like cystic fibrosis), all of their children will have the following odds of inheriting it:

25% chance of being heterozygous normal and not carrying the recessive allele (AA)

50% chance of being a healthy carrier (Aa)

25% chance of having the genetic disorder (aa)

	A	**a**
A	**AA**	**Aa**
a	**Aa**	**aa**

Explore INVESTIGATION B4

❸ Checking the predictions

1. Now, to simulate the randomness of inheritance, you will flip coins to see if your predictions are right. The first trait you will flip for is sex. Choose the male sex chromosome coin (X on one side and Y on the other) and the female sex chromosome coin (X on both sides). Flip the coins onto the table and record your results in the actual genotype column of Table 1. For the other traits, you'll need to use the correct egg and sperm coins for each parent. Use the data in Table 1 to find the parents' genotype for each trait. Then, select the egg and sperm coins that have the correct alleles for that genotype. For example, if the father's genotype for skin color is TT, choose the sperm coin that has a capital T on both sides of the coin. If the mother's genotype for skin color is tt, find the egg coin that has a lower case t on both sides of the coin.
2. Flip the coins onto the table. Record your results in column 6 of Table 1.
3. Use Table 2 to look up the corresponding phenotype. Record the phenotype of the offspring in the last column of Table 1.
4. Repeat this procedure for all the traits.
5. Build your creature and compare with other creatures in the class.

❹ Developing and using models

a. Why do you need to choose different egg and sperm coins for each trait and for each parent?

You need to choose the correct egg and sperm coin because each trait is determined by its own set of alleles.

b. How many of the actual phenotypes matched your predicted phenotypes? Explain your results.

Answers will vary. Sample answer: Ten of my predictions matched my actual results. Seven of the traits had 100% probability of being one of the traits so I was sure that I had those predictions correct. The traits that were split (50%) forced me to guess. I was right two times in that situation.

c. Which parent does your offspring share the most traits with, the mother, father, or both equally?

Answers will vary. Sample answer: My creature shares nine traits in common with its mother and seven traits in common with its father.

Explore INVESTIGATION B4

d. Are Punnett squares unnecessary if both parents have the same genotype? Explain.

It depends on what genotypes the parents have. If both parents are TT or tt, then the Punnett squares are unnecessary. If both parents are Tt, then you need to use the Punnett square.

e. What are the possible percentages for probability when using Punnett squares? Explain why these are the only possibilities.

The possible percentages are 100%, 75%, 50%, 25%, or 0% when using Punnett squares. These are the only possibilities because each parent has two alleles, which can combine four possible ways in the offspring.

f. From your investigation, what genotypes will you recommend to NASA for the initial breeding pair for their new exhibit? Explain your choices.

Answers will vary. Sample answer: I would recommend Tt for all traits for the parents. When two Tt parents are crossed, there is the greatest chance for diversity of traits in the offspring. Some offspring will show the dominant phenotype, while some will show the recessive phenotype. If the parents are TT or tt for any trait, that will limit the amount of variation and cause the offspring to have a higher chance of resembling the parents.

❺ Exploring on your own

Make an informational sign to display at the NASA educational exhibit explaining Punnett squares and probability to the public. Your sign should show the genotypes and phenotypes of the parents. It should also explain why this pair was selected. Also, be sure to include the appropriate Punnett squares to show the predictions for the possible offspring.

Answers will vary. Sign should include the genotypes and phenotypes of the parents. It should explain why this pair was selected. It should include the Punnett squares to show the predictions for the possible offspring.

Guiding the INVESTIGATION

❹ Developing and using models

The goal of this part of the investigation is to reinforce the idea that Punnett squares are useful in making predictions about heredity, but because heredity is random, they are not a guarantee of genotypes and phenotypes of the offspring.

WRAPPING UP

Internet search There are many websites that will help students find out how to make Punnett squares. Instruct students to use a search engine and type in the words "Punnett square tutorial." Once they have mastered the process, have students write a list of instructions on how to make a Punnett square.

Evaluate

INVESTIGATION **B4**

Name _____ Date _____

1. What is the phenotype for a Crazy Creature with a genotype of TT for beak?

   Trumpet beak

2. What is the genotype for a Crazy Creature with mouse ears?

   tt

3. If a homozygous dominant (TT) parent mated with a homozygous recessive (tt) parent, what is the probability of the offspring having the dominant phenotype? Show the Punnett square with your answer.

   100% dominant

4. If a heterozygous (Tt) parent mated with a homozygous recessive (tt) parent, what is the probability of the offspring having the homozygous recessive (tt) genotype? Show the Punnett square with your answer.

   50% recessive genotype

5. Why couldn't two Crazy Creatures with separate eyebrows ever produce an offspring with a unibrow? Explain your answer using a Punnett square.

   Two tt parents for eyebrows could never produce an offspring with a unibrow because they don't have a dominant allele to contribute. At least one parent would need to have a dominant allele (and thus a unibrow) in order to have an offspring with a unibrow.

6. Can a pure dominant (TT) parent and a mixed-allele (Tt) parent ever produce a pure recessive (tt) offspring? Explain your answer using a Punnett square.

   No, because one parent (TT) is always going to donate a dominant allele to the offspring. This means that the offspring will display the dominant phenotype no matter what the other parent has for a genotype.

Question 3:

	T	T
t	Tt	Tt
t	Tt	Tt

Question 4:

	T	t
t	Tt	tt
t	Tt	tt

Question 5:

	t	t
t	tt	tt
t	tt	tt

Question 6:

	T	T
T	TT	TT
t	Tt	Tt

Notes and Reflections