The Teosinte Hypothesis

OVERVIEW

This lesson supplements the BioInteractive short film *Popped Secret: The Mysterious Origin of Corn* by providing students with a better understanding of the mathematics behind Dr. Beadle's genetics research. Students will use Punnett squares to model crosses if one, two, or three genes are involved in determining the differences between teosinte and maize. Then, they develop a mathematical model to make further predictions, and use those to explain the main conclusion of Dr. Beadle's research and how it supports his hypothesis about maize's origins.

KEY CONCEPTS

- The hypothesis that teosinte is the wild ancestor of maize is supported by genetic evidence.
- Understanding how genes are inherited allows scientists to make predictions about the frequency of inherited traits in offspring.

STUDENT LEARNING TARGETS

- Calculate and predict the probability of offspring genotypes and phenotypes based on genetic crosses.
- Compare different methods of modeling genetic predictions.

CURRICULUM CONNECTIONS

Standards	Curriculum Connections
NGSS (2013)	HS-LS3-3, HS-LS4-3; SEP2, SEP4, SEP5
AP Bio (2015)	3.A.3; SP1, SP2, SP5
IB Bio (2016)	3.4, 10.2
Common Core (2010)	Math.A-CED.1, Math.S-IC.2; MP1, MP4, MP8
Vision and Change (2009)	CC3; DP2, DP3

KEY TERMS

allele, genotype, maize, phenotype, Punnett square, teosinte

TIME REQUIREMENTS

Two 50-minute class periods.

SUGGESTED AUDIENCE

- High School: Biology (General, AP/IB)
- College: Introductory Biology

PRIOR KNOWLEDGE

Students should be familiar with:

- the genetic basis for inheritance
- working with exponents and algebraic expressions

TEACHING TIPS

- Depending on your students' experience, you may choose to do this activity as a class so that students are clear about how to complete a Punnett square. If students have already been introduced to Punnett squares, you can have them work individually or in teams of two or three.

- You may want to have students watch the film before beginning this activity. Encourage them to write down questions they have about the film's content. Suggest that they read all the questions in the activity before they watch the film again in class. Then, when students watch the film again at the start of this activity, they can focus on the specific questions that relate to this activity. If you only have time to watch the film once, encourage students to take notes as they watch. If time allows, replay certain sections most pertinent to the activity once it's completed and answer any remaining questions.
- If you wish to guide your students through the mathematical model, have students do through the "Two Genes?" section alone or in small groups and then do the "Three Genes?" and "A Better Way?" sections as whole group instruction.
- In previous work with Punnett squares, students may have considered dominant and recessive traits. If your students have experience with some examples of non-Mendelian inheritance, you may wish to point out that the pattern of inheritance for the teosinte/maize cross looks similar to incomplete dominance or co-dominance in which the heterozygotes have a phenotype in between the two parental extremes for a trait. Another way of stating this relationship is called an additive model of inheritance. In an additive model, the measured phenotype of a heterozygote is the average between the phenotypes of the two homozygous parents. For example, if teosinte makes two rows of kernels on a cob and maize makes eight, the heterozygote would have five rows. Later genetic experiments with maize and teosinte showed that the genes that differ between the two species mostly act in an additive fashion. Only one major gene acts in a simple Mendelian fashion.
- If necessary, remind students that the maize and teosinte plants are diploid, meaning that offspring from the cross receive one copy of each maize chromosome and one copy of each teosinte chromosome.
- The film uses the phrase "copy of the gene" to refer to what each parent organism contributes to offspring. This lesson is using the more familiar term *allele*. An allele is a version of a gene or any stretch of inherited DNA. In either case, you may want to probe your students' understanding to make sure they are using appropriate terms.
- You may want to review some of the different representations for alleles. Biologists use a range of symbols to represent alleles. Typically, when students first learn about Mendelian patterns of inheritance, they see dominant and recessive symbols for alleles (*A*, *a*, respectively). Biologists also use symbols that do not denote dominance (for example, A1 and A2, A_1 and A_2, or A^1 and A^2 for two alleles of the gene A). Alleles are also sometimes represented using a nucleotide that differs between the alleles (for example, A, G). Some representations are more complex, such as the alleles for human ABO blood type (I^A, I^B, i), which is used to show the two codominant alleles (I) and the recessive O allele (i), using superscripts to distinguish the two different codominant alleles. Other representations for alleles exist in addition to those described.
- This activity (Question 14 in particular) provides an opportunity to address the common misconception that probability equals outcome. Although the probability of a given genotype may be one of every four offspring (for example), in reality, it is possible that the cross would result in four heterozygous individuals or even four individuals with the same genotype as one of the parents. Punnett squares predict probability only. Remind students of the law of large numbers from statistics, which suggests that populations with small sample sizes may show results that are quite different from expected results due to sampling error. If one measured hundreds or even thousands of offspring from a cross of F_1 plants, you would have a much better chance of seeing the ratios in offspring predicted by the Punnett square.
- Through this activity, students should gain an understanding of how quickly the amount of genetic variation increases as the number of genes involved goes up. In later steps of the activity, students will use what they have learned to identify patterns related to this increase. For this reason, the total number of genetic combinations (from both parents) is included as well as an indication of the number of unique genotypes (disregarding which parent contributed which copy of the gene).

ANSWER KEY

One Gene?

1. Using the allele symbols A^T and A^M, complete the Punnett square below by following these steps:
   a. Identify the genotype of the F_1 parent plants in Figure 3. ***A^TA^M***
   b. Write down the alleles that each parent contributes to the cross in the spaces provided on the sides of the Punnett square (note that if one gene controls the phenotype, each parent contributes one of **two** possible alleles).
   c. Determine the possible genotypes of the F_2 offspring and fill in the Punnett square.

	A^T	A^M
A^T	A^TA^T	A^TA^M
A^M	A^TA^M	A^MA^M

2. If offspring homozygous for the A^T allele (A^TA^T) look just like teosinte, and offspring homozygous for the A^M allele (A^MA^M) look just like maize, identify:
   a. the ratio and percentage of offspring expected to look just like teosinte ***1/4, 25%***
   b. the ratio and percentage of offspring expected to look just like maize ***1/4, 25%***
   c. the ratio and percentage of offspring expected to have a combination of teosinte and maize characteristics ***1/2, 50%***
3. Which Punnett square — the one you drew, or the one in Figure 3 — do you find more informative? Explain your answer. ***Answers will vary.***

Two Genes?

4. Using allele symbols A^T/A^M and B^T/B^M, complete the Punnett square below by following these steps:
   - Identify the genotype of the F_1 parent plants in Figure 3. ***A^TA^M B^TB^M***
   - Write down the alleles contributed by each F_1 parent in the spaces provided on the sides of the Punnett square (note that if two genes are involved, each parent contributes one of **four** possible allele combinations).
   - Determine the possible genotypes of the F_2 offspring and fill in the Punnett square.

	A^TB^T	A^TB^M	A^MB^T	A^MB^M
A^TB^T	$A^TA^TB^TB^T$	$A^TA^TB^TB^M$	$A^TA^MB^TB^T$	$A^TA^MB^TB^M$
A^TB^M	$A^TA^TB^TB^M$	$A^TA^TB^MB^M$	$A^TA^MB^TB^M$	$A^TA^MB^MB^M$
A^MB^T	$A^TA^MB^TB^T$	$A^TA^MB^TB^M$	$A^MA^MB^TB^T$	$A^MA^MB^TB^M$
A^MB^M	$A^TA^MB^TB^M$	$A^TA^MB^MB^M$	$A^MA^MB^TB^M$	$A^MA^MB^MB^M$

5. How many **different** F_2 genotypes are there? List the genotypes and identify whether each genotype would result in a phenotype that looks just like maize (i.e., has only maize alleles), looks just like teosinte (i.e., has only teosinte alleles), or looks like a mix of the two.
   Nine:
   - *$A^TA^T B^TB^T$; looks just like teosinte*
   - *$A^TA^T B^TB^M$; looks like a mix*
   - *$A^TA^T B^MB^M$; looks like a mix*
   - *$A^TA^M B^TB^T$; looks like a mix*
   - *$A^TA^M B^TB^M$; looks like a mix*
   - *$A^TA^M B^MB^M$; looks like a mix*
   - *$A^MA^M B^TB^T$; looks like a mix*
   - *$A^MA^M B^TB^M$; looks like a mix*
   - *$A^MA^M B^MB^M$; looks just like maize*

6. Based on your answers to the previous questions, identify:
   a. the ratio and percentage of offspring expected to look just like teosinte *1/16, 6.25%*
   b. the ratio and percentage of offspring expected to look just like maize *1/16, 6.25%*
   c. the ratio and percentage of offspring expected to look like a mix of teosinte and maize *14/16 or 7/8, 87.5%*

Three Genes?

7. Using allele symbols A^T/A^M, B^T/B^M, and C^T/C^M, complete PART of the Punnett square below following these steps:
   a. Identify the genotypes of the F_1 parent plants in Figure 3. $A^TA^M B^TB^M C^TC^M$
   b. Write down the possible alleles contributed by each F_1 parent in the spaces provided on the sides of the Punnett square (note that if three genes are involved, each parent can contribute any of **eight** combinations of alleles).
   c. Circle the genotypes from each parent that only have alleles from teosinte.
   d. Fill in the F_2 genotypes of the offspring that would result from this one cross in the Punnett square.
   e. Circle the genotypes from each parent that only have alleles from maize.
   f. Fill in the F_2 genotypes of the offspring that would result from this one cross in the Punnett square.

	$A^TB^TC^T$	*$A^TB^TC^M$*	*$A^TB^MC^M$*	*$A^TB^MC^T$*	*$A^MB^TC^T$*	*$A^MB^TC^M$*	*$A^MB^MC^T$*	*$A^MB^MC^M$*
$A^TB^TC^T$	*$A^TA^TB^TB^TC^TC^T$*	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype
$A^TB^TC^M$	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype
$A^TB^MC^M$	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype

$A^TB^MC^T$	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype
$A^MB^TC^T$	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype
$A^MB^TC^M$	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype
$A^MB^MC^T$	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype
$A^MB^MC^M$	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	F_2 genotype	*$A^MA^MB^MB^MC^MC^M$*

8. Identify the ratio and percentage of offspring expected to look just like teosinte by following these steps:
   a. How many F_2 genotypes did you fill in for the cross between F_1 parents with only teosinte alleles? *1*
   b. Take the total number of teosinte-like F_2 individuals and divide it by the total number of F_2 possibilities in the overall Punnett square. Identify the ratio and percentage of offspring expected to look just like teosinte. *1/64, 1.56%*

A Better Way?

9. Do you notice the pattern? What proportion of F_2 offspring would you expect to look just like teosinte if four genes controlled the differences between maize and teosinte? Explain your answer.
   1/256 because 4^4 is 256.

10. Write a formula in the following format to capture your model: $x = y/z^w$. Define each of the variables or replace them with constants (numerals).
    $x = 1/4^w$ or an equivalent expression
    x = probability that an F_2 offspring will look just like teosinte
    $y = 1$
    $z = 4$
    w = number of genes responsible for the differences between teosinte and maize

11. Use your formula (and show your work) to predict the proportion of F_2 offspring expected to look exactly like teosinte if:
    - 5 genes were involved *$1/4^5 = 1/1{,}024$*
    - 10 genes were involved *$1/4^{10} = 1/1{,}048{,}576$*
    - 100 genes were involved *$1/4^{100} = 1/1.6 \times 10^{60}$*

12. How would the probability of an offspring inheriting all its alleles from teosinte compare to the probability of an offspring inheriting all its alleles from maize? Explain your answer.
The probabilities would be identical because the teosinte parent and the corn parent contribute the same number of alleles to their offspring. So an offspring has the same probability of inheriting all its alleles from teosinte as it does for inheriting all its alleles from maize.

Dr. Beadle's Results

13. Use evidence from your mathematical model to support or refute Dr. Beadle's conclusion that four or five genes are involved in causing the differences between teosinte and maize.
According to the model, if four genes were involved, 1/256, or about 195/50,000, F_2 plants should have looked just like teosinte. If five genes were involved, then 1/1,024, or about 49/50,000, F_2 plants should have looked just like teosinte. In the experiment, 1/500, or 100/50,000, F_2 plants looked just like teosinte. 100 is between 195 and 49.

14. A student club replicates Dr. Beadle's experiment, but on a much smaller scale. They grow 500 F_2 plants. They did not find any that looked just like teosinte. Does that mean Dr. Beadle's conclusion was wrong about the genetics of teosinte and maize? Explain why or why not.
No, it does not mean Dr. Beadle was wrong. The model predicts that there is a 1/500 probability that F_2 plants would look just like teosinte. But probability does not guarantee an outcome, especially in small groups where you can get sampling error. A 1/500 probability is very small, and with only 500 F_2 plants grown, there just didn't happen to be one that inherited only teosinte alleles. You would have a better chance of seeing that outcome in a bigger group of F_2 plants, like the one Dr. Beadle studied.

REFERENCE

Doebley, J. "The Genetics of Maize Evolution." *Annual Review of Genetics* 38, 1 (2004): 37–59. https://doi.org/10.1146/annurev.genet.38.072902.092425.

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