Introduction for Teachers

*Note: this introductory material is the same as that on Worksheet 1, but the annotations **in** the worksheet below are unique to Worksheet 2. If you used Worksheet 1, you can skip this intro and go straight to the annotated worksheet that starts on page 3 below.*

Respect the Punnett!

This set of worksheets can serve to introduce students to using a Punnett square as a tool to answer questions such as, *Given parents' genotypes, what are the phenotypes of the offspring and the probability of an offspring with each phenotype?*

It is important to recognize that the Punnett square is an elegant shortcut for this, and that the correct answer relies on solving a multi-step problem. That is, it requires an understanding of 1) meiosis, 2) random assortment, 3) fertilization, 4) converting genotype to phenotype, 5) calculating proportions. And yet, a Punnett square may seem simple!

It seems simple, because it is an elegant simplification of a set of events that we, as teachers and biology lovers, could recite backwards in our sleep with both hands tied behind our backs. Although... that *would* make it difficult to sleep... but we could still do the reciting part.

Because of our familiarity with this intricate series of events, we have not given the Punnett square the **respect** it is due.

The Punnett square is actually a very elegant algorithm for starting with two genotypes and getting to the probability of any possible offspring phenotype. It's elegance is based on its simplicity, the way it accurately condenses the 5 steps above into a 2 x 2 matrix of possibilities.

Note that the square itself does not actually tell you the phenotypes; you need to know the inheritance pattern for the gene in question. Nor does it calculate the proportions and hence the probabilities of each phenotype, though to us, with four outcomes, that seems trivial to do in our heads. Nevertheless, when you tell students to do a Punnett square it is inevitable that they will need to perform the genotype to phenotype operation, and calculate the proportions, which are not trivial for them, especially at first.

We introduce the Punnett to students as a tool, and they use it as such—generally without understanding that they are "simulating" the 5 processes above—to plug in the alleles and get the right answer. But if you ask for reasoning, for a demonstration of the understanding of the answer, it may not be there. When crossing two heterozygous parents, and posing that there are three offspring with the dominant phenotype, how many of your students assume that the fourth offspring *will* have the recessive phenotype? When breeding such parents in a simulation, how many will repeat the cross until the ratios “work out right”?

Below you will find 2 worksheets that can be used to lead students as a class, in pairs, or individually to an understanding of the 2 x 2 matrix approach as a sure-fire way to simulate all the possibilities inherent in meiosis & fertilization. The first one, *Shortcut to All Possible Combinations,* does not use chromosomes or a biological context, which may make the logic easier to follow. The second one, *The Possibilities of One from Mom, One from Dad*, uses drake chromosomes and can be a follow up, or used independently if you prefer not to leave a biological context in the first place.

Following these two worksheets, students will still need to be able to to convert genotype to phenotype and then tally up the phenotypes to create a ratio, as well as learn the difference between probability of outcome and certainty of outcome. However, the critical step of understanding the logic behind the 2 x 2 matrix - that is represented in the worksheets as taking one object at a time and pairing it with the other set, each in turn, will set students up to understand why they are drawing a box, then making four boxes inside it, and writing alleles on the outside.

You may want to make changes to these worksheets and we are very interested in what changes you would make. Please share them with us! We will read each and every one, incorporating updates to create revised versions that we hope everyone will find useful.

Thank you for joining us on this journey as we make genetics more meaningful to students, empowering them to reason about genetics and obtain deeper, more robust understanding of a vital topic in biology.

The Geniventure Team

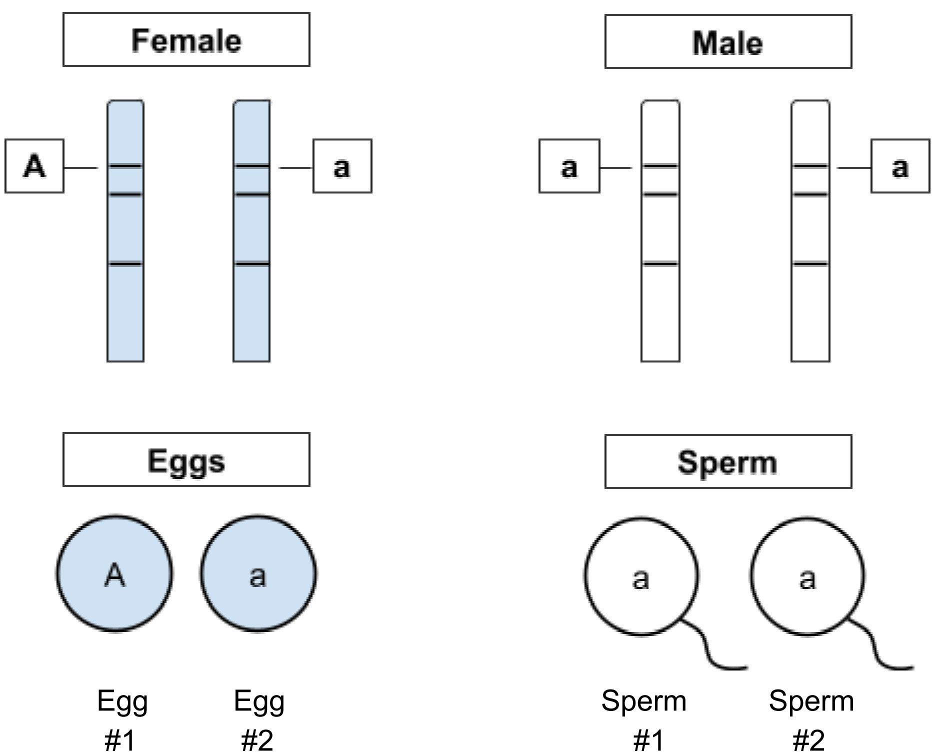
PS: The following worksheets are the Teacher’s Edition and contain highlighted annotations for teacher use; the student versions of the worksheets are in a separate file.

The Possibilities of One from Mom, One from Dad

Every drake has three pairs of chromosomes. In sexual reproduction, males make sperm and females make eggs. Each sperm and egg gets a copy of ONE out of the two chromosomes of each pair that the parent has. This means that each drake sperm and each drake egg has three chromosomes. When the sperm fertilizes the egg, the offspring then has three **pairs** of chromosomes. For each pair, one came from the Mom's egg, and one came from the Dad's sperm. It works the same way in humans, although we have 23 pairs of chromosomes.

Let's look at how this works with just one of the three drake chromosomes. Our goal is to figure out every possible way that these chromosomes could be paired up in an offspring drake.

Here are the pairs of chromosome #1 for female and male drake parents. The arms allele is marked with an uppercase 'A' and the armless allele is marked with a lowercase 'a'. Below the chromosomes are the eggs and sperm that these drakes can make. This female can produce eggs with either allele. The male can only produce sperm with the armless allele.



In the eggs and sperm, instead of showing the whole chromosome, we are showing just the allele letters.

STEP 1: It's important to be sure that we have covered all the possible eggs and sperm that can be created by these two parents, for this allele. Are these the only possibilities? Explain your

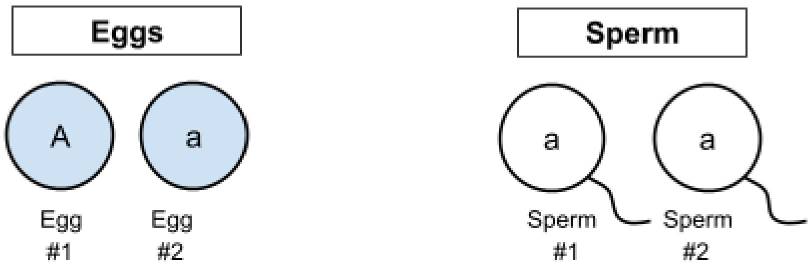
answer. [*Exemplar answer: Yes, because in meiosis, only one chromosome goes into a egg or sperm cell and it can be either one, so we have to consider both possibilities.*]
STEP 2: Find all the possible *combinations* of eggs and sperm. You may draw or write out the combinations in any form you choose. The goal is to list or draw every way that an egg and a sperm can combine to create an offspring genotype. Explain how you arrived at your answer in words.Refer to any drawings that might help explain your answer.

[*Exemplar answer: Students may use an arrow diagram or draw lines from the pairs of cards to new combinations, or make lists.]*

Notes:
Students may not do this successfully, and that is OK at this stage.
*Encourage **all** students to look for missing combinations or duplicate combinations, but do not correct them if they are wrong. They will correct themselves later.*

If students have had Punnett squares previously, they may draw one. However, especially if they do, they should explain in words how it works.

STEP 3: Use tables as a shortcut to listing all the possibilities. Take one egg and pair it up with each of the two sperm. Use the table below.



Sperm → Egg ↓	a Sperm #1	a Sperm #2
A Egg #1		

STEP 4: Repeat STEP 5 with the **other** egg.

Sperm → Egg ↓	a Sperm #1	a Sperm #2
a Egg #2		

STEP 5: Combine the two tables into one.

Sperm → Egg ↓	a Sperm #1	a Sperm #2
A Egg #1		
a Egg #2		

STEP 6: Think it through.
The table above holds four egg/sperm pairs. Each of these pairs represents a fertilized egg that can lead to an offspring. When you are working with two parents and chromosome pairs, will there **always** be four possible ways they can combine into a fertilized egg? Explain your answer.

Challenge problem: An alien species has pairs of chromosomes, like we do, but they reproduce with *three parents* instead of two!

Show how we can predict all the possible combinations of these three parents' pairs of chromosomes:

[Two Punnets with an extra allele added in will cover the possibilities.]

	A	*a*
A	*AAA*	*AaA*
a	*AaA*	*aaA*

	A	*a*
A	*AAa*	*Aaa*
a	*Aaa*	*aaa*

OR

Challenge problem: An alien species has *three of each chromosome* instead of a pair. When they reproduce, there are two sperm that fertilize one egg.

Show how we can predict all the possible combinations of these three parents pairs of chromosomes:
A 3 x 3 matrix will provide the answer.

	A1A2	*A2A3*	*A1A3*	*(sperm)*
eggs				
A1				
A2				
A3				