LEARNING FROM THE FRUIT FLY

A CARD GAME FOR TEACHING MENDEL'S LAWS, MEIOSIS, AND PUNNETT SQUARES

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The fruit fly (*Drosophila melanogaster*) is an ideal subject for studying inheritance patterns, Mendel's laws, meiosis, Punnett squares, and other aspects of genetics. Much of what we know about genetics dates to evolutionary biologist Thomas Hunt Morgan's work with mutated fruit flies in the early 1900s (DNA Learning Center 2011). Many genetic laboratories throughout the world still use fruit flies today (Carlson 2004).

Fruit flies are sometimes used in the classroom, but because live stocks can be difficult to maintain, we developed an activity that substitutes fruit fly cards for live fruit flies. This article describes how to make these cards and implement the activity, which aligns with the *Next Generation Science Standards* (NGSS Lead States 2013; see box, p. 47).

Laboratory investigation: Materials

We created fruit fly cards for students to study the inheritance patterns of three different traits (Figure 1) using six different samples (Figure 2). Three generations were modeled: P1 (the original parents), F1 (offspring from P1), and F2 (offspring from F1 self-cross). We started with public domain images found on Wikipedia of wild type male and female fruit flies (see "On the web"). We modified the images using Microsoft Paint to represent the various mutations taught in class (Figure 3). To make cards measuring 5 cm × 5 cm (2 inch × 2 inch), we printed the images on white cardstock and manually cut them out. (A quicker option is to print them on business card sheets.)

We labeled all cards with sample number and generation (P1, F1, or F2) and sorted the cards by sample but not by generation. We used about 30 flies for each sample (Figures 4 through 6, pp. 42–43). If more realistic fruit fly generation size is desired, multiply the sample sizes by 5 or 10. The finished cards can be laminated for use in future classes.

Students can complete a worksheet (see "On the web") during the activity, recording data, describing observed patterns, and preparing for class discussion. The worksheet provides a formative assessment.

Materials for each group of 2–4 students:

- Set of cards (all samples and generations; see Figure 3 for number of cards)
- Worksheet (see "On the web")
- Sex identification chart (see "On the web")

Laboratory investigation: Procedure

Students devoted four two-hour class periods to this activity. The activity also could be done in eight 50– to 60–minute class sessions or could be modified if less time is available. For instance, Day 1 could be split over two class periods with one day on data collection and the next day on answering questions and class discussion. The following describes what students should know before the activity, the lesson plans of each day, and suggested summative assessment.

Before the activity

Key concepts of mitosis should be taught and assessed first. In class discussion, explore the concept of chromosomes as pieces of information, emphasizing that new daughter cells are identical to the parent cells. This is important because students will later distinguish between asexual and sexual reproduction.

FIGURE 1

Fruit fly mutations covered in class.

Mutation	Mode of inheritance	Mutant genotype	Corresponding wild-type genotype
No wings (Apterous)	Autosomal recessive	ww	WW, Ww
Sepia eyes	Autosomal recessive	rr	RR, Rr
White eyes	X-linked recessive	X^eX^e	X^EX^E, X^EX^e

FIGURE 2

Mutation of interest for each sample. All samples were contained in each set of cards.

Sample	Mutation(s) of Interest
1	No wings
2	No wings
3	Sepia eyes and no wings
4	Sepia eyes and no wings
5	White eyes
6	White eyes

Day 1: Data collection

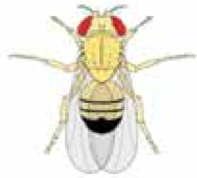
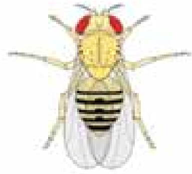
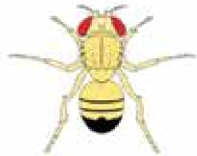
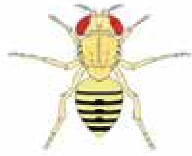
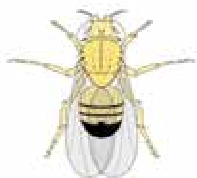
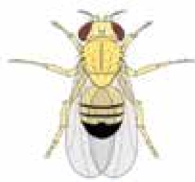
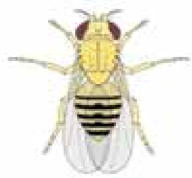
We ask: "How do fruit flies inherit traits from one generation to another?" To answer this, students must cross fruit flies and see what appears within the offspring. We explain that students will model fruit fly mating with cards. The instructor may also explain the historical significance of fruit fly genetics and Morgan's work.

Before students begin, we explain the different generations: The two individuals from the P1 generation were mated to create the F1 generation. Then a male and female from the F1 generation were crossed to create the F2 generation. The sex identification chart is then explained, along with how to fill in the data tables in the worksheet (note that Punnett squares are not used until Day 3). After this introduction, students lay out the cards by generation for each sample (Figure 7, p. 44) and record on the worksheet the number of fruit flies of each provided phenotype and sex. Students typically can collect the data with ease, even when using a sex identification chart created to sex real flies.

After collecting data and before class discussion, students complete questions 1–5 on the worksheet, which consist of recording general patterns and writing possible explanations for the patterns. Students notice that the flies from the F1 generation are like some of the parents and that traits reappear in the F2 generation, similar to the findings of Mendel.

FIGURE 3

Graphics and number of cards per set for each type of fruit fly.

Trait	Male		Female	
	Graphic	# of Cards	Graphic	# of Cards
Wild type		72		81
No Wings		8		12
White Eyes		19		6
Sepia Eyes		5		4
Sepia Eyes and No Wings		4		3

We connect the idea about the fly crosses to the simple crosses Mendel did with pea plants because the students had read about Mendel and his laws for an earlier assignment. During discussion, students often do not recognize the connection between the inheritance patterns and Mendel's laws, making scaffolding necessary.

Alternatively, students could begin the activity without previous exposure to Mendel's observations or laws and be required to describe any possible patterns. The instructor could use the patterns that students provide to explain Mendel's laws. These observations support how both parents contribute to the traits of their offspring during sexual reproduction, which is different from what they recently learned regarding mitosis.

Day 2: Mendel's laws and meiosis

We begin the next class by having students describe the main findings from the previous day. We emphasize that Mendel developed the law of segregation and law of independent assortment through the patterns he observed after many crosses and large sample sizes. Since scientific laws are observed relationships among factors of a phenomenon, and scientific theories explain how these observations can occur, we ask what are the "theories" explaining Mendel's laws. Given that scientists now know about homologous chromosomes, Mendel's laws can easily be explained through the model of meiosis and the chromosome theory of inheritance.

This is an opportunity to explicitly address the nature of science, specifically the functions of and distinctions between scientific laws and theories.

We present the purpose and stages of meiosis using two homologous pairs of chromosomes, pointing out that although fruit flies have four pairs, we are focusing on two for simplicity. Once the phases are drawn on the board, we have students talk within their groups about how meiosis and chromosome theory can explain why the law of segregation occurs. Then we scaffold class discussion, emphasizing the actions during anaphase 1, which is when the "traits," or, as we now know, homologous chromosomes, separate from each other, eventually into separate gametes.

Students are then ready to answer questions 6–8 on the worksheet. These questions cover samples 3 and 4, which illustrate the interaction of two different genes on different, non-homologous chromosomes. Students identify patterns in the fruit fly data. In the F2 generation, all possible combinations of the two traits occur; the offspring do not have to look like previous generations since they do not have to have the same combination of traits as their parents.

Then we ask how this can occur by asking if they can predict in what order the homologous chromosomes will line up during metaphase 1 of meiosis. By examining the stages of meiosis, students typically realize it cannot be predicted, and therefore, any order is possible. Once students realize that the order cannot be predicted, we have them consider how this information helps to explain why independent assortment occurs. With some scaffolding, students can explain that the random ordering of homologous pairs explains why independent assortment occurs.

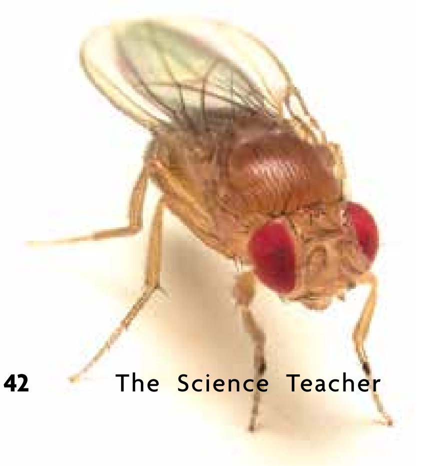


FIGURE 4

Number of "fruit flies" for samples 1 and 2.

The P1 generation of both samples was a homozygous wild type fly (has wings) and a homozygous mutant fly expressing the "no wing" trait. Variation between samples 1 and 2 is if the male or female had the wild type trait.

		Sample 1		Sample 2	
		With wings	No wings	With wings	No wings
P1	Male	0	1	1	0
	Female	1	0	0	1
F1	Males	8	0	11	0
	Females	9	0	6	0
F2	Males	3	2	4	1
	Females	4	2	4	2

FIGURE 5

Number of "fruit flies" for samples 3 and 4.

The P1 generation of both samples was a homozygous wild type fly (has wings and red eyes) and a homozygous mutant fly expressing both the "no wings" trait and "sepia eye" trait. Variation between samples 3 and 4 is if the male or female had the wild type trait.

Sample 3					
		Red eyes & wings	Red eyes & no wings	Sepia eyes & wings	Sepia eyes & no wings
P1	Male	0	0	0	1
	Female	1	0	0	0
F1	Males	7	0	0	0
	Females	6	0	0	0
F2	Males	7	2	2	2
	Females	6	3	2	1

Sample 4					
		Red eyes & wings	Red eyes & no wings	Sepia eyes & wings	Sepia eyes & no wings
P1	Male	1	0	0	0
	Female	0	0	0	1
F1	Males	6	0	0	0
	Females	6	0	0	0
F2	Males	6	2	3	1
	Females	6	4	2	1

FIGURE 6

Number of "fruit flies" for samples 5 and 6.

The P1 generation of both samples was a homozygous wild type fly (has red eyes) and a homozygous mutant fly expressing the "white-eyed" trait. Variation between samples 5 and 6 is if the male or female had the wild type trait.

		Sample 5		Sample 6	
		Red eyes	White eyes	Red eyes	White eyes
P1	Male	0	1	1	0
	Female	1	0	0	1
F1	Males	9	0	0	9
	Females	12	0	12	0
F2	Males	3	4	6	5
	Females	8	0	4	5

Day 3: Punnett squares

After spending a day on meiosis and Mendel's laws of inheritance, we apply both concepts to Punnett squares. We begin by reviewing meiosis and defining key terms (Figure 8, p. 44). We use meiosis to describe how to set up Punnett squares (i.e., how to determine the gametes that will be crossed by means of the Punnett square). Then, as a class, we confirm this process by creating Punnett squares of the F1 and F2 generation for samples 1 through 4 on the worksheet (Figure 9, p. 45), as well as novel examples.

During these exercises, we emphasize the connection between meiosis, Punnett squares, and phenotype and genotype ratios. Students typically struggle with the connection between meiosis and Punnett squares. They want to go directly to a "plug and chug" approach without considering the origin of the gametes they use in the crosses. By referring to the fly crosses, we ask students to demonstrate the formation of gametes from each parent, and then set up the Punnett square with those gametes (see sidebar at left). Students tend to grasp this connection fairly quickly once they are required to model meiosis for the fly crosses. After students do the fruit fly Punnett squares, they complete a worksheet of Punnett square practice problems that require an illustration of meiosis to determine the gametes. During this activity, students often need assistance on determining the gametes that are then used to set up the Punnett square.

How do meiosis and Mendel's laws of inheritance apply to Punnett squares?

Before creating Punnett squares, the first step is to determine the gametes that will be formed from each parent. An example is the F1 cross of sample 1 (Figure 9, p. 45). The heterozygous F1 flies of sample 1 (Ww), while phenotypically "winged," produce gametes with the dominant form, W, and gametes with the recessive form, w, through the process of meiosis. These are the gametes they then use to model the cross through use of the Punnett square that will produce the F2 generation.

A more complex example comes with fly samples 3 and 4, which involve two traits generated by genes on non-homologous autosomal chromosomes. For example, the F1 cross of sample 3 is a dihybrid cross, RrWw x RrWw. By modeling meiosis, the following gametes are possible: RW, Rw, rW, rw. A point of emphasis for this exercise is that there are many cells undergoing meiosis for each fly; thus the ratio of gamete formation is equal for the four possible types. When required to go through meiosis with the F1 flies, if the law of independent assortment is not applied, then only one round of meiosis is done, which yields just two possible types of gametes, depending on how the homologous chromosomes are lined up during metaphase 1. Observations with the F2 generation, however, are evidence to support the notion that all four types of gametes must be included in the F1 cross. Therefore, the law of independent assortment is used to provide an explanation and evidence for the occurrence of four possible types of gametes.

FIGURE 7

Students lay out the cards by generation for each sample.

FIGURE 8

Key genetic terms defined for students on Day 3.

Term	Definition
Trait	General characteristic (e.g., eye color) that is determined by one or more genes.
Allele	Particular variant of a gene (we're diploid, so each person has two alleles per gene, but there can be many possible alleles in a population).
Dominant allele(s)	Allele that is not completely masked by another allele.
Recessive allele(s)	Allele that can be masked by dominant allele.
Heterozygote (heterozygous)	Individual with two different alleles for a specified gene.
Homozygote (homozygous)	Individual with two of the same alleles for a specified gene.
Homozygous Dominant	Two identical dominant alleles for a specified gene.
Homozygous Recessive	Two identical recessive alleles for a specified gene.
Genotype	Specific combination of alleles of an individual.
Phenotype	How the trait appears.

FIGURE 9

Punnett square answers for each sample.

Differences between samples 1 and 2, 3 and 4, and 5 and 6 were due to whether the parent male or female carried the wild type trait. Therefore, Punnett squares are the same for samples 1 and 2 and samples 3 and 4 but different between samples 5 and 6 since the latter were x-linked.

Samples 1 and 2

F1 Generation (Gametes from P1)

	W
w	Ww

F2 Generation (Gametes from F1)

	W	w
W	WW	Ww
w	Ww	ww

Samples 3 and 4

F1 Generation (Gametes from P1)

	WR
wr	WwRr

F2 Generation (Gametes from F1)

	WR	Wr	wR	wr
WR	WWRR	WWRr	WwRR	WwRr
Wr	WWRr	WWrr	WwRr	Wwrr
wR	WwRR	WwRr	wwRR	wwRr
wr	WwRr	Wwrr	wwRr	wwrr

Sample 5

F1 Generation (Gametes from P1)

	X^E
X^e	$X^E X^e$
Y	$X^E Y$

F2 Generation (Gametes from F1)

	X^E	X^e
X^E	$X^E X^E$	$X^E X^e$
Y	$X^E Y$	$X^e Y$

Sample 6

F1 Generation (Gametes from P1)

	X^e
X^E	$X^E X^e$
Y	$X^e Y$

F2 Generation (Gametes from F1)

	X^E	X^e
X^e	$X^E X^e$	$X^e X^e$
Y	$X^E Y$	$X^e Y$

Day 4: Sex chromosomes

After students are familiar with meiosis, Mendel's laws, and Punnett squares, they learn about several genetic inheritance models that do not follow basic Mendelian patterns. We use the fruit fly card data (Figure 6, p. 43) and the worksheet questions nine through 11 to introduce sex-linkage. Students first look at the crosses produced for the fifth and sixth samples and describe how the inheritance appears different than what they have already seen. Students observe that there are now differences in sex ratios. We have asked students in the past why the observations are different, but they typically are not sure where to even begin.

We then describe sex chromosomes. We construct a Punnett square with just the X and Y chromosomes and then show how they can be labeled with alleles of certain genes (e.g., X^E). Then we have students go back to the fruit fly example and create the Punnett squares (Figure 9, p. 45) and compare to the data they gathered. The data do not exactly match the expected ratios. This was intended, so that the data are more realistic, which allows for a conversation with students about how natural populations do not exactly follow model predictions. Their comparisons, nevertheless, confirm the result of the Punnett squares.

Summative assessment

Students are summatively assessed on both content and application for this activity. For instance, they are asked to apply what they learned about meiosis and Punnett squares to novel examples and describe Mendel's laws, the theories behind the laws, and evidence from novel fruit fly data that supports the theories (see "On the web" for our assessment questions). Another option is to have students design their own organism and describe how its traits are passed to the next generation.

Although students struggle with using fruit fly data as evidence of Mendel's laws on a quiz taken at the beginning of Day 3 of the activity, students' application greatly improves on the unit exam. For example, question #3 in the "Relevant Assessment Questions" document (see "On the web") asks students to explain which characteristics of generations F1 and F2 illustrate the law of segregation and law of independent assortment. Most students answered the question incorrectly on the quiz but, later, on the exam, were able to describe which data illustrate which law.

Conclusion

Overall, students enjoy this hands-on activity. Data collection goes more quickly and smoothly than using real fruit flies. Moreover, data from all generations can be collected at once by using the fruit fly cards. In the past, while working with real flies, students had to wait two weeks between data collections. By then we had moved past the topic, making the activity more of a verification lab than part of the learning process for meiosis, inheritance patterns, and genetic crosses. As instructors, we like that the cards can be used every semester and that we no longer have to travel to school in the middle of the night to mate fruit flies. Using cards, we can adjust the types of flies and the number of different phenotypes/genotypes per generation as needed to teach a variety of genetic crosses. ■

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On the web

Original fruit fly images: *http://bit.ly/Fruit-fly*

Image files of each fruit fly in Figure 3, embedded in a Word document: *www.nsta.org/highschool/connections.aspx*

Relevant assessment questions with answers: *www.nsta.org/highschool/connections.aspx*

Sexing *Drosophila*: *https://arrogantscientist.wordpress.com/sexing-drosophila/*

Student worksheet: *www.nsta.org/highschool/connections.aspx*

References

Carlson, E.A. 2004. *Mendel's legacy: The origin of classical genetics*. Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press.

DNA Learning Center. 2011. DNA from the beginning: Chromosomes carry genes. *www.dnaftb.org/10/animation.html*

NGSS Lead States. 2013. *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

Standards
HS-LS3 Heredity: Inheritance and Variation of Traits

Performance Expectations
The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.
HS-LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.
HS-LS3-2. Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.
HS-LS3-3. Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population.

Dimension	Name and *NGSS* code/citation	Specific Connections to Classroom Activity
Science and Engineering Practices	**Engaging in Argument From Evidence** • Make and defend a claim based on evidence about the natural world that reflects scientific knowledge, and student-generated evidence. (HS-LS3-2) **Analyzing and Interpreting Data** • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. (HS-LS3-3)	Students explain how the collected data supports Mendel's laws. Students compare collected data to probabilities created using Punnett squares.
Disciplinary Core Ideas	**LS3.A: Inheritance of Traits** • Each chromosome consists of a single very long DNA molecule and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function. (HS-LS3-1) **LS3-B: Variation of Traits** • In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. (HS-LS3-2)	Students describe the mechanism (including function of chromosomes, DNA, and genes) that cause patterns observed in the collected data. Students discuss how the patterns observed in the collected data and Mendel's laws are a result of processes that occur during meiosis.
Crosscutting Concept	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS3-1), (HS-LS3-3)	Students explain that the processes that occur during meiosis cause the resulting phenotypic effects.