Learning genetics *with* paper pets

by Valerie Raunig Finnerty

By the end of the eighth grade, students are expected to have a basic understanding of the mechanisms of basic genetic inheritance (NRC 1996). However, these concepts can be difficult to teach. The related activities often require a lot of time and involve the use of living organisms, which some may view as unethical. To teach my seventh- and eighth-grade students about genetics and the inheritance of traits, I adapted a one-period activity from our science text (Cronkite et al. 2000). This activity helps students explore the inheritance of genetic traits over multiple generations, the role and effects of genetic mutations, the origin and impact of genetic diseases, and the methods used to predict and track the inheritance of genetic traits.

In this investigation, students create paper creatures with a specified set of genetic traits, "breed" them, predict characteristics of offspring with and without mutations, and explore natural selection and evolution. All that is required for the activity is paper, a double-sided counter (coin), and art materials such as markers, colored pencils, or crayons. Used as a supplement to regular classroom study, the paper pet activity takes approximately 15 to 20 minutes several times a week during an eight-week unit on genetics, but the activity can be expanded or reduced to fit the needs of a particular classroom. Genetic features of paper pets are added as the students learn about them in their regular course of study.

Introduction to inheritance

At the beginning of the unit, students conduct a quick self-assessment to catalog the presence of particular inheritable traits, such as the presence or absence of a widow's peak, attached earlobes, hitchhiker's thumb, dimples, and the ability to roll the tongue. **Safety Note:** Using PTC to test an individual's "taster" gene is no longer recommended. See the online version of this article at *www.nsta.org* for an in-depth explanation. A follow-up discussion revolves around what students know about why members of a family share characteristics and how they think these traits are passed from one generation to the next.

CAUTION

Next, students read about nineteenth-century monk Gregor Mendel's work with inheritance in pea plants, and are introduced to terminology such as *parent generation*, *F1 generation*, *genotype*, *phenotype*, *dominant trait*, *recessive trait*, and *allele*, as well as the techniques of Punnett Squares for determining the probability of inherited traits

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in offspring. After this introduction, I give each student a copy of a worksheet (see page 21) with directions on how to make a paper pet parent.

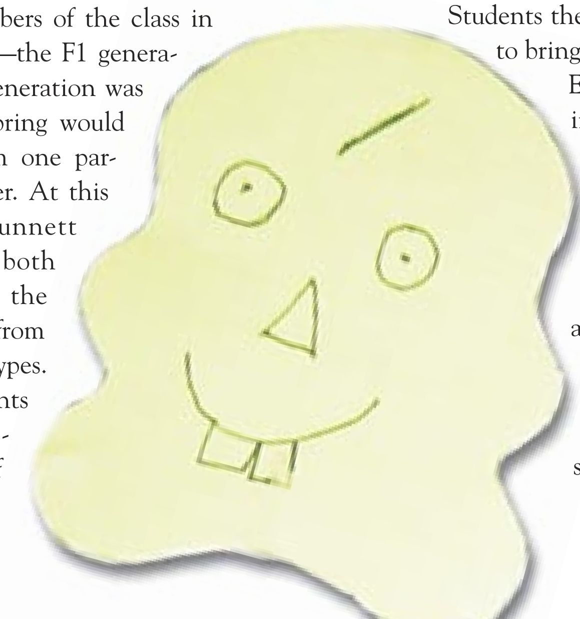
Students make their paper pet parents at home, using the template provided. They use colored pencils, crayons, or markers to color them, and often add creative touches of their own such as sequins, feathers, cloth, and glitter. I stored the paper pets in plastic shoeboxes, labeled with the generation (P, F1, and so on), but large plastic bags would also work.

The parent (P) generation has five genes that students needed to take into account: body color (blue or yellow), gender (male or female), eye shape (round or square), nose shape (triangular or oval), and teeth shape (pointy or square). Students are able to choose which form of each trait they want to assign their parent paper pets, but the parent paper pets are homozygous for each trait (they have two forms of the allele for each trait). The dominant traits are blue color, round eyes, pointy teeth, and triangular nose, so the genotype for a P generation pet that was a yellow male with round eyes, a triangular nose and square teeth would be as follows: bb, XY, CC, TT, pp. On the back of their paper pets, students record the genotype, pet's name, their own initials, and a "P" to indicate the generation. Then they decorate the front to reflect the phenotype.

After admiring students' P generation pets, which are often quite creative, I tell them that I will randomly pair their pets with other members of the class in order to produce offspring—the F1 generation. Because the parent generation was all homozygous, their offspring would simply get one allele from one parent and one from the other. At this point, I reintroduced Punnett squares as a method of both recording and predicting the characteristics of offspring from parents with specific genotypes. In their notebooks, students record the names, genotypes, and phenotypes of the P generation parents and their offspring. They then construct Punnett squares to describe the possible genotypes for each trait in the F1 generation. To determine the gender of offspring, students flip a double-sided counter to model the 50 percent chance of the father paper pet passing down either an X or a Y chromosome. The paper pet offspring have a slightly smaller body template used for the F1 generation and all future generations. The offspring activity sheet on page 22 is the worksheet with directions for determining the genetic characteristics of the paper pet offspring. I remind students to make sure that their initials and the generation are printed on the back of each paper pet. At the end of class I collect the pets and store them in a plastic bin labeled F1. Alternatively, students could keep their own paper pets in labeled envelopes.

Genetics and probability

After producing the F1 generation, students should understand dominant and recessive traits and be able to determine possible outcomes using Punnett squares. The mating of the F1 generation adds both complexity and interest to the activity, because most of the F1 paper pets are heterozygous for one or more traits. F1 paper pets are chosen to mate by pulling them randomly from the F1 container. Only male/female pairs that are not closely related can mate. In a larger class, students can hold onto their F1 pets and trade several of them with other students. To determine which allele will be passed from parent to offspring, students use a double-sided counter (coin). For example, if the father paper pet is blue Bb, the student flips the counter; one side indicates that the dominant allele will be passed down, and the other side that the recessive allele will be passed down. If a parent is homozygous for a trait, then the parent simply passes a copy of the allele to their offspring. This is done for each trait and for each offspring. In class, students determine the genotypes and phenotypes for their F2 generation and record them on the templates. Students then finish making their paper pets at home to bring in the next day.



Each student brings four F2 paper pets in to class to share the greater phenotypic variety of this generation. The purpose and usefulness of the Punnett squares become clearer as we discuss the meanings of probable, improbable, and impossible outcomes. Students are able to clearly see that some traits are more likely than others to be passed on to offspring. Students record the information for their new offspring in their science notebooks.

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Mutations

I collect the F2 paper pets and tell students that the next time we work with the paper pets some mutations will have occurred. Before the next class, I randomly choose four paper pets and change the color genotype of each one so that one allele is now an R. I then choose four different paper pets and change the eye shape genotype—so that one allele is now an S (in other words, I adjust the mutation rate so that approximately 5 to 10 percent of the paper pets carry the mutation). For example, a female paper pet with the genotype bb, XX, Rr, Ss, pp would now be Rb, XX, Rr, Ss, pp.

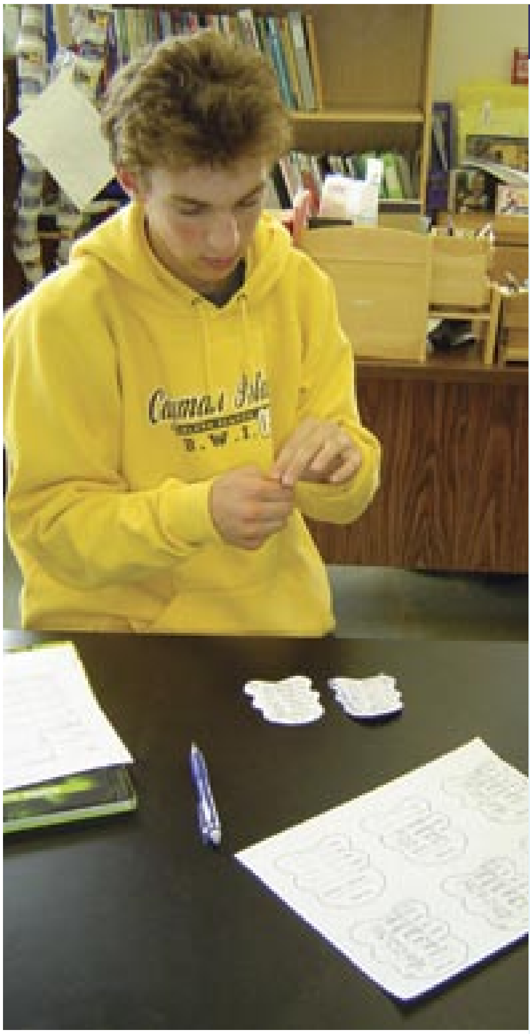
The next time that we work with the paper pets, I ask students to discuss with a partner their understanding of mutation. We share definitions as a class and I explain that a mutation is a change in the coding of a gene that affects the message carried by that gene. I also add that some mutations can be harmful, some helpful, and some neutral. We discuss examples of each category of mutation, and I tell the students that we all have mutations, but that the only mutations that can be passed on to offspring are those that occur in a sex cell.

At this time I announce that several of the F2 paper pets have experienced mutations in their sex cells. The first mutation was for a red color and was expressed with an R. I explain that red was codominant with blue and dominant over yellow in paper pets with the result that a paper pet with the genotype BR would be

A family gathering of paper pets.

FIGURE 1 **Summary of the gene pool of paper pets**

Trait	Alleles/genotype	Phenotypes	Dominance/notes
Color	B b R	blue yellow red	dominant recessive dominant over yellow, codominant with blue to create purple
Gender	XX XY	female male	
Spotted nose malady (sex-linked genetic trait)	XZ Xz	nonlethal, some spots lethal, many spots 50% chance of death for XzXz or XzY	dominant recessive
Eye shape	C c S	round square star	dominant recessive dominant over both
Nose shape	T t	triangle oval	dominant recessive
Teeth shape	P p	pointed square	dominant recessive
Albinism	A a	regular color albinism	dominant recessive (If an individual is homozygous for albinism (aa), they will be albino, regardless of their genotype for color



purple, and one with the genotype RR or Rb would be red. I explain that the second mutation was for eye shape and was written S. The S mutation results in star-shaped eyes, and is dominant over both round and square eyes.

Students are then eager to mate the F2 paper pets to create four F3 generation paper pets and then four F4 generation paper pets. Students trade their F2 paper pets to obtain mating pairs. As before, they record their paper pets' genotype and phenotype in their science notebooks. I also introduce the use of a pedigree as a tool at this point to show the inheritance of a trait through multiple generations. Each student creates a pedigree to show where a recessive trait seen in one of their F4 paper pets had come from. This necessitates the borrowing of other students' breeding records and underscores the importance and purpose of good record keeping.

Making a paper pet parent

Follow the directions below to create a paper pet parent with five inheritable traits.

The following traits are possible:

Paper pet inheritable traits		
Color	Blue	Yellow
Gender	Male	Female
Eyes	Round	Square
Nose	Triangular	Oval
Teeth	Square	Pointy

Materials

- rectangle of blue or yellow paper, about 11 × 14 centimeters
- scissors
- glue
- markers or colored pencils
- materials to decorate the paper pet (buttons, feathers, sequins, fabric, other colored paper, and so on)

Directions

1. On the rectangle of blue or yellow paper, trace a paper pet body and cut it out.
2. If the paper pet is male, draw a straight line for hair at the top of the head. If it is female, draw a squiggly line for hair at the top of the head.
3. Give the paper pet square or round eyes, a triangular or oval nose, and square or pointy teeth.
4. Copy the following chart onto the back of the paper pet:

Pet's name:		
Trait	**Phenotype**	**Genotype**
Color		
Gender		
Eyes		
Nose		
Teeth		

5. In the first column, list the paper pet's phenotype (blue or yellow, male or female, round eyes or square eyes, triangular nose or oval nose, and square teeth or pointy teeth).
6. In the second column, list the paper pet's genotype. Use "BB" for blue, "bb" for yellow, "XY" for male, "XX" for female, "CC" for round eyes, "cc" for square eyes, "TT" for a triangular nose, "tt" for an oval nose, "PP" for pointy teeth, and "pp" for square teeth. (In the parent generation, all of the paper pets are homozygous).
7. You may decorate the rest of the paper pet as you wish, as long as it correctly reflects its phenotype. Be creative!
(adapted from Cronkite et al. 2000)

Making paper pet offspring

Follow the directions to make paper pet offspring.

Materials
- two paper pet parents (one male and one female)
- coin or double-sided counter
- rectangles of blue and yellow paper, about 7 × 10 centimeters
- scissors
- glue
- markers or colored pencils
- materials to decorate the paper pet (buttons, feathers, sequins, fabric, other colored paper, and so on)

Directions
1. To determine which color your offspring will be, determine which allele will be represented by each side of your coin or double-sided marker. For example, heads could be B, and tails could be b. If your parent paper pet is homozygous for a trait (for example, BB or bb), then they will simply pass on one of the alleles to their offspring. However, if your parent paper pet is heterozygous for a trait (for example, Bb), then your coin toss will determine which allele is passed down. Remember that B is dominant and b is recessive.
2. Cut out a paper pet shape from the appropriate color and copy the following chart onto the back:

Pet's name:		
Trait	**Phenotype**	**Genotype**
Color		
Gender		
Eyes		
Nose		
Teeth		

3. Write in the phenotype and genotype for color.
4. Determine the gender of the offspring by flipping the coin to find out which chromosome (X or Y) is passed on by the male parent. The female parent passes on an X. Fill in the gender phenotype and genotype on the chart.
5. Use the coin or double-sided marker to determine the alleles inherited by the offspring for the other three traits. Remember that round eyes (C), triangular nose (T), and pointy teeth (P) are dominant forms of the traits. Fill in the phenotype and genotype for each trait on the chart.
6. Decorate the front of the paper pet offspring to reflect the inherited traits. You may add other features and decorations. Be creative!
7. Use the same procedure to determine the traits of all offspring. Remember that each offspring is the result of a separate process of inheritance.

(adapted from Cronkite et al. 2000)

More mutations

As we continue to study genetics, I add a sex-linked genetic disease (spotted nose malady) and multigenic traits (albinism) to the genetic pool in the paper pets (see Figure 1 for a summary of the paper pet traits) for a F5 generation. Although the effort needed to determine the genetic makeup of offspring becomes more complicated, students are able to keep track of the multiple constraints on the phenotype of their offspring. Many other mutations could be used including size, shape, hairiness, and so on.

Extensions

I continue to use paper pets as we begin our evolution unit. First, to demonstrate artificial selection, students designate a target phenotype and then selectively breed paper pets to produce the desired traits in their offspring. They find that some phenotypes require repeated cross breeding and inbreeding over several generations in order to produce the desired traits.

To model natural selection, I use a yard each of four different fabrics picturing a desert scene, a coral reef, a jungle, and a boreal forest. The fabric cost about $10, but alternatively, the teacher or students could draw habitat scenes on large pieces of paper. I put all of the F5 generation in the jungle and give students an information page listing the environmental pressures found in this habitat and the adaptive and maladaptive traits (see Figure 2).

Students trade their paper pets for mating, but before students create offspring, they need to determine the parents' potential for reproductive success. The number of adaptations possessed by the pair is used to determine the number of offspring that would be produced. Each pair starts off with two offspring, but for each adaptive trait that both parents have, one more offspring is produced, and for each maladaptive trait that both parents have, one less offspring is produced. Some students' paper pets are very successful and pro-

FIGURE 2 **Natural selection in the jungle habitat**

Paper pets are now living in a jungle habitat. The jungle has dense foliage, and as a consequence is very dark and moist. The many large tree species provide nuts that are the paper pets' main source of food. Most of the trees have evolved thick nutshells to protect the nuts from herbivores like the paper pets.

Within the paper pet gene pool, there is a diverse collection of alleles. Some of these alleles code for phenotypes that are adaptations; that is, they allow the paper pet to thrive in the jungle environment. Other alleles code for phenotypes that are maladaptive; paper pets with these traits are less likely to survive and reproduce. Finally, other alleles code for phenotypes which are neutral, and code for traits that do not give the paper pets distinct advantages or disadvantages in the jungle environment.

The following phenotypes are either adaptive or maladaptive for success in the jungle environment:

Phenotype	Environmental pressure	Adaptive?
Dark colors (blue, purple, red)	predators in the dark, dense foliage	yes
Light colors (white, yellow)	predators in the dark, dense foliage	no
Oval nose allows the paper pets to produce a deeper, more resonant mating call that reverberates through the dense foliage.	dense foliage muffles sound	yes
Triangle nose allows the paper pets to produce a shrill, weaker whistle that does not carry very far.	dense foliage muffles sound	no
Pointed teeth allow paper pets to pierce thin-skinned fruits and suck out the juice.	main food source is nuts with thick shells	no
Square teeth allow paper pets to crush thick-shelled nuts.	main food source is nuts with thick shells	yes

Each paper pet starts out with the ability to produce two offspring per litter. For every adaptation possessed by the parents, one more offspring is produced. For every maladaptation possessed by the parents, one less offspring is produced.

duce as many as nine offspring, and other students' only produce one or none.

After the students create the F6 generation in the rain forest habitat, I introduce the other three habitats. We discuss each habitat and students decide upon several environmental pressures and the adaptive traits for each. I then divide the F6 generation randomly among the four habitats. Students then create the F7 and F8 generations in each habitat, using natural selection to determine reproductive success. Although definite differences can be seen between populations of paper pets in different habitats, the students realize that many more generations are needed before the populations are substantially different. This is a good model for speciation through natural selection.

Conclusion

My students were highly invested in the paper pets activity. Their interest and enthusiasm did not flag during the eight weeks of the genetics unit or during the six-week unit on evolution. Not only was their long-term work with paper pets motivating, but it was also a powerful learning tool. On their end-of-unit test, my students exhibited a strong understanding of the concepts of genetic inheritance, mutations, and probability, often referring to their experiences with the paper pets to back up their answers. The paper pets activity also provided them with a hands-on opportunity to explore the connections between genetic variation, natural selection, and evolution. ■

References

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academy Press.

Cronkite, D., I. Miaoulis, M. Cyr, and M.J. Padilla. 2000. Teaching resources with color transparencies. In *Science explorer: Cells and heredity*, eds. D. Cronkite, I. Miaoulis, M. Cyr, and M.J. Padilla. Needham, MA: Prentice Hall.

Resources

Determining Your Genes activity—*student.biology.arizona.edu/sci-conn/heredity/worksheet_heredity.html*