

ScienceNews

IN HIGH SCHOOLS | EDUCATOR GUIDE

Gene drives **UNLEASHED**



SOCIETY FOR
SCIENCE & THE PUBLIC

About the article

The *Science News* article “Gene drives unleashed” examines the potential of a new genetic tool called CRISPR/Cas9 to alter genes rapidly across a wild population, perhaps ending some of the world’s greatest health and ecological scourges. There are many potential benefits to humanity, but scientists are also examining and debating the potential for unforeseen consequences.

Because this article is longer than what is typically used in a classroom, this guide has been designed to focus on the first two sections of the article, including the introductory and “Rule breakers” sections. Educators are encouraged to use this guide according to their time and resources and the level of their students.

“Gene drives unleashed” can be used across a wide range of curricula, with a focus on **biology** with some review of **probability** from middle school. The activities, questions and discussions in this educator guide can be used to support the following education standards:

Next Generation Science

Heredity: Inheritance and Variation of Traits: [HS-LS3-1](#), [HS-LS3-2](#), [HS-LS3-3](#)

Common Core

ELA Standards: [Writing Literacy in Historical/Social Studies and Science and Technical Subjects](#) (WHST): 1, 2, 7, 9

ELA Standards: [Writing](#) (W): 7, 8, 9, 10

ELA Standards: [Speaking and Listening](#) (SL): 1, 2, 4, 6

ELA Standards: [Language](#) (L): 4

ELA Standards: [Reading for Literacy in Science and Technical Subjects](#) (RST): 1, 2, 4, 6

ELA Standards: [Reading Informational Text](#) (RI): 1, 7

Prior to reading

Guide student reading by pointing out connections between this article and what students are learning in class. Here, find ideas for standard-aligned paths to follow while reading:

- Ask students what they know about cellular reproduction. Do they know the difference between *mitosis* and *meiosis*? How does meiosis yield an offspring with a unique combination of genetic information? What do students know about how this process relates to inheritance? What factors determine whether a particular trait will be passed on and become widespread in future generations?
- Encourage students to consider the difference between a “wild” population and a population in the lab or in captivity. How might the populations differ? How do humans interact with one versus the other (*Studying them in the field versus in the lab; direct versus indirect manipulation of the populations*)? What are the benefits and consequences of those interactions?
- Mosquitoes are annoying, but do students also know that they can be dangerous? Do students know why the mosquito bite itches? (*Unlike bees and wasps, which inject a venom when they sting, the mosquito injects an anticoagulant that prevents blood from clotting. The anticoagulant leads to a small allergic reaction.*) Do they know that mosquitoes can transmit malaria, which kills nearly half a million people a year, as well as other diseases including dengue, West Nile virus and yellow fever? (*Students can visit the website of the [Centers for Disease Control and Prevention](#) to research diseases and their prevalence around the world.*)
- Ask students to think about how people have tried to prevent the spread of diseases throughout human history. Students might consider the rise of hospitals, vaccines and quarantine facilities. They might talk about improvements in hygiene, travel restrictions, public awareness and education. Have populations across the globe benefited equally from these developments? Why or why not?

After reading: Comprehend

You can adapt and print these questions ([Blackline Master 1](#)) to check for comprehension and analysis before or after discussion:

1. **What is the main topic of the first two sections of the article?** (*A new technique for genetic engineering, known as CRISPR/Cas9, is making gene drives possible.*)
2. **What are gene drives?** (*Engineered DNA designed by scientists to insert itself into an organism and spread quickly through a population, forever altering offspring.*)

3. **What makes CRISPR/Cas9 revolutionary?** (*This new technology is faster and more efficient than previous techniques; it is flexible enough to edit genes from a range of organisms.*)
4. **What concerns does the article raise about the use of CRISPR/Cas9 for gene drives?** (*There could be unforeseen consequences that permanently alter ecosystems. The use of this technology needs to be considered from an ethical and regulatory standpoint.*)

After reading: Analyze

1. **Examine the diagram “Inheritance advantage,” page 17. After studying the diagram, explain in your own words how gene drive inheritance differs from normal inheritance.** (*Under normal inheritance, a mosquito with an altered gene has a 50% probability of passing this gene on to its offspring. Under gene drive inheritance, the copy on one chromosome inserts itself into the other chromosome, so there is a greater than 50% probability that the gene will be passed on to offspring.*)
After considering the process, what factors might influence how quickly the altered gene spreads through the population? (*Answers might include: how reliably the gene drive inserts itself into the second chromosome; how many gene drive mosquitoes there are in the population to begin with; how much those gene drive mosquitoes mate relative to the typical mosquitoes; the organism’s mutation rate.*)
2. **Using what you know, why is the speed and efficiency of the CRISPR/Cas9 system important? Can you think of other technologies that didn’t take off until they became more fast and efficient?** (*In many ways, word processing on the computer is a more efficient version of the typewriter; today’s printers are much easier to use and faster than the original printing press; early cellular phones were clunky and not many people had them, but today’s phones have greater functionality.*)
3. **An acronym is an abbreviation formed from the first letter of each word from a phrase. The acronym is pronounced as its own word. CRISPR stands for “clustered regularly interspaced short palindromic repeats.” Do you think this is a good acronym? Can you come up with a better one?**

Discuss and Assess

After students read the article independently, return as a group to the concepts outlined prior to reading. Invite students to share their answers and observations from the article and lead a class discussion that further underscores your current curriculum. The discussion can serve as an informal assessment. Ideas for further reading discussion or writing prompts include:

- Gene editing with CRISPR/Cas9 is a powerful new technology. How has genetic engineering been used in the past to produce novel or improved organisms? (*Students might examine how genetic engineering has been used in medicine, for the production of insulin and gene therapies, for example; its use in agriculture, for the production of drought-resistance crops, boosting yields and pest-resistance; its use in lab animals, for the study of how genes function and for studying diseases.*) Ask students to brainstorm their own ideas for how CRISPR/Cas9 could be used. What problems do they think this technology could solve?
- Ask students to consider the idea, “Just because we can, doesn’t mean we should” in light of this story. Consider leading a classroom debate on the pros and cons of genetic engineering, in general, or the use of gene drives specifically. In addition to researching the benefits, students will research potential unintended consequences, risks to human health or environmental impacts of human meddling throughout history. See [Blackline Master 2](#) for a sample debate protocol.
- What procedures might scientists implement to prevent “unforeseen consequences”? What would be the benefits and consequences of those procedures? (*Scientists could be required to have a reversal or stoppage protocol before any gene drive is released; before release, gene drives might have to go through FDA approval, or approval of some other regulatory body; limitations could be placed on the type of gene drives—for example, a species can be altered so it doesn’t carry a disease but can’t be driven to extinction.*)

Extend Offer students other ways to explore the content of the article as it relates to your curriculum, such as:

VOCABULARY BUILDING

- Researchers use specific terminology for scientific concepts and to explain their ideas. Introduce your students to some ideas and words from the article that might be unfamiliar. You can use [Blackline Master 3](#) to guide students through a vocabulary activity.

PUNNETT SQUARES

- In the 1860s, Gregor Mendel proposed the principles of segregation and independent assortment. Reginald Punnett, the British geneticist who the Punnett square is named for, understood that each parent contributes an allele for any given gene to the gamete (egg or sperm cell). These alleles can be homozygous or heterozygous, and by examining all the possible combinations of alleles, the probability that offspring have a particular genotype can be determined. Your students can use [Blackline Master 4](#) to trace the probability of particular genotypes over multiple generations. For an online lab about Gregor Mendel and his work with pea plants, [visit this link](#) from the Education Development Center.

MARSHMALLOW INHERITANCE

- **Purpose:** Students create their own “genetic offspring,” first by tracing normal inheritance and then with an example of gene drive inheritance.
- **Prior knowledge:** Students may know that DNA, found inside the nucleus of nearly all cells, has important genetic information. Cells may reproduce either sexually or asexually. When reproduction is sexual, DNA from each parent contribute to the genetic information of the offspring, resulting in a unique set of inherited traits.
- **Potential misconceptions:** Students often confuse terms like *genotype* and *phenotype*, *homozygous* and *heterozygous*.
- **Notes to teacher:** This is a simplified simulation. Because inheritance depends on probabilities, the outcomes cannot be predicted exactly.
- **Materials for class:**
 - Large marshmallows
 - Small marshmallows (3 colors)
 - Thumbtacks
 - Pushpins with colored plastic heads
 - Pipe cleaners
 - Small nails
 - Toothpicks
 - Paper towels
- **Materials for each student pair:**
 - [Blackline Master 5 and 6](#)
 - An envelope containing:
 - One set of the [Blackline Master 7](#) duplicated onto pink paper, each piece cut out
 - One set of the [Blackline Master 7](#) duplicated onto blue paper, each piece cut out
(*These cutouts represent a complete set of chromosomes.*)

■ Procedures:

Normal inheritance

1. Decide how you will make the class materials available to students. Will they be passed out or available at a station?
2. Begin by asking students, “Where do our genes come from?” (*We get half of our genetic information from each parent.*) Take a moment to review the relationship between chromosomes, genes and alleles. (*There can be many genes on one chromosome, and genes exist in different forms, called alleles.*)
3. Distribute [Blackline Master 5](#) to students and have them preview what they will be doing.
4. Give students their envelopes, have them follow the directions on the handout and record the genotype information.
5. The students will then build their offspring.
6. When students have built their offspring, have them observe their own and compare it with the offspring created by other students.
Ask: Were your offspring created through sexual or asexual reproduction? What are the dominant traits that your offspring inherited? Does your offspring have any recessive traits? What does it mean when an organism is homozygous or heterozygous for a trait? (*An organism is homozygous for a trait if it inherited the same allele from both parents. An organism is heterozygous for a trait if its alleles differ, if, for example, one is dominant and one is recessive.*) Have students chart the number of offspring with curly versus straight tails.
7. Have students place all the chromosomes back in the envelope.

Gene drive inheritance

1. Tell students that they are now going to build an offspring with gene drive inheritance. Distribute [Blackline Master 6](#).
2. Have them select alleles as they did in the first trial.
3. Tell students that in this round of inheritance there is a new rule. If they have a creature that is heterozygous for tail shape (Tt), the gene drive will convert the T allele to a t allele, resulting in a tt combination.
4. After applying this rule, have students build their new offspring and compare it with the offspring created by other students.
Ask: How is the new offspring different from the previous offspring? How is it the same? Are there any new patterns that emerge across the offspring of the entire class? Have students chart the number of offspring with curly versus straight tails. How did the gene drive inheritance affect the offspring? Ask students what they would expect to observe in future generations under normal inheritance, and then under gene drive inheritance.
5. Have students place all the chromosomes in the envelopes and collect them.

This exercise was inspired by: [Reebop genetics, first described by the University of Wisconsin.](#)

Comprehend

After reading the article, "Gene drives unleashed," answer these questions:

1. What is the main topic of the first two sections of the article?
2. What are gene drives?
3. What makes CRISPR/Cas9 revolutionary?
4. What concerns does the article raise about the use of CRISPR/Cas9 for gene drives?

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Debate protocol

There are many debate structures and protocols, most notably the Lincoln-Douglas and parliamentary debates. (See this link from the [National Speech & Debate Association](#) for more examples.) In most classes, a less formal structure is desired. We recommend the following protocol, which will encourage student engagement and participation and will help students develop a more persuasive voice that can be used orally and in writing.

■ **Prepare three debate topics.**

For example, students can debate:

- the pros and cons of genetic engineering (in general)
- gene drives (specifically)
- the eradication of disease
- specific limits that might be placed on scientists doing research in this area

■ **Form students into groups of three.**

Three groups will work together to form a team:

- one group takes the affirmative argument
- one group takes the negative argument
- one group acts as judge and timekeeper

■ **Provide the first topic for the debate and give all teams 15 minutes to research and brainstorm their arguments.**

■ **The judge panel moderates the debate between the two groups within their team:**

- a member of the affirmative group has three minutes to speak
- a member of the negative group has three minutes to speak
- a different member of the affirmative group has three minutes to respond
- a different member of the negative group has three minutes to respond
- the last member of the affirmative group has three minutes to sum up
- the last member of the negative group has three minutes to sum up

■ **The judge panel records the strong points and decides which argument was most persuasive. The judging group should decide:**

- which side they agree with
- how their views were informed by the debate
- effective strategies used by those debating
- suggestions for strengthening the next debate

■ **The winning group becomes the judge group for the next round, during which the other two groups debate the next topic.**

■ **The winner of the second debate then debates the winner of the first, to determine the team leader.**

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Vocabulary support

Biologists use words to help them communicate scientific ideas clearly. Knowing how to break words into familiar pieces can help you understand what the words mean and where they came from. How do scientists use and create language to tell a story?

Here are two examples:

1. **Endangered:** the prefix *en-* means “in,” *-ed* makes the word past tense, so *endangered* means “was or has been put in danger.” An endangered species has become in danger of extinction.
2. **Herbicide:** *herb* refers to plants and *-cide* refers to a killer. Therefore, an *herbicide* is a substance that is toxic to vegetation.

Now for something harder:

3. **Microbial:** How can you break this word up? What does it mean?

4. **Genetics:** *gen* comes from *genesis*, meaning “origin,” or *genea*, meaning “generation.” Why do you think this word was used for *genetics*, the study of genes? What is a geneticist? What is a genome?

5. **Chromosome:** *chromo* is the Latin form of the word *khroma*, meaning “color.” What is a chromosome? How do you think chromosomes came to be called that?

6. What words from the article are unfamiliar? Use your knowledge of word parts and origins to try to decipher their meanings.

Punnett squares

Directions:

Use the tables to determine the probability that a trait will be expressed for each generation.

Generation 1

Gregor Mendel planted a pea plant homozygous for yellow seeds (YY) and one homozygous for green seeds (yy). What do the offspring look like?

		Mother	
		Y	Y
Father	Y	Yy	Yy
	y	Yy	Yy

100% of offspring will be heterozygous Yy. It is known that yellow seeds are dominant over green seeds, so all the seeds will be yellow.

Generation 2

Select two offspring from generation 1 and allow them to pollinate. What are the probabilities for the offspring?

		Mother	
		Y	y
Father	Y		
	y		

- ___ % will express yellow seeds (homozygous)
- ___ % will express yellow seeds (heterozygous)
- ___ % will express green seeds (homozygous)
- ___ % will express green seeds (heterozygous)

Generation 3

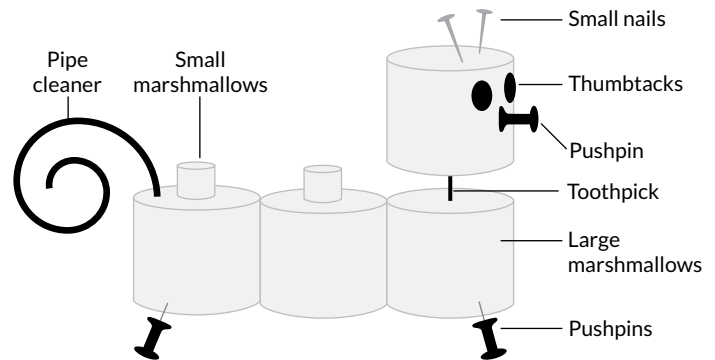
What might the third generation look like? How many Punnett squares will you need to map all the possibilities based on generation 2? Draw out and explain your own solution.

Marshmallow inheritance

Directions: You will construct a marshmallow creature using the principles of Mendelian inheritance.

■ Procedure for normal inheritance:

1. Work with a partner. Each of you represents a parent of your offspring.
2. Inside your envelope are both female and male alleles for genes found on the chromosomes. Remove the alleles and place them on your table so no letters are showing (face down).
3. If you are the female, select one pink paper representing each shape. If you are the male, do the same with the blue shapes. Put the unselected papers back into the envelope. They won't be used. Think about what this represents.
4. The papers out on the table represent the alleles on the chromosomes in the egg and sperm. When they unite, they form a zygote. Match up the pairs of alleles (corresponding shapes) and turn over your pairs.
5. Highlight the genotypes of your offspring in the chart below.



■ Genotype table:

Genotype	Phenotype	Genotype	Phenotype
AA	2 antenna	Aa	1 antenna
aa	No antenna	mm	1 body hump
Mm	2 body humps	MM	3 body humps
QQ	Red nose	Qq	Orange nose
qq	Yellow nose	TT, Tt	Curly tail
tt	Straight tail	EE, Ee	2 eyes
ee	3 eyes	LL, Ll	Blue legs
ll	Red legs	DD, Dd	3 body segments
dd	2 body segments		

6. Use the genotypes to determine the phenotypes.
7. Build your offspring using the materials provided.

■ Discuss:

8. Compare your offspring with those from other pairs of parents.
9. Were any of the offspring identical?
10. Is there any trait that showed up in every offspring?
11. What does it mean when an organism is homozygous or heterozygous for a trait?
12. Chart how many offspring across the class have curly tails versus straight tails.

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Marshmallow inheritance

Directions: You will again construct an offspring from two parents, but this time typical Mendelian inheritance will be modified by the introduction of a gene drive. The gene drive is designed so that whenever you or your partner end up with an offspring heterozygous for a curly tail (Tt), the T allele becomes a t allele, resulting in tt.

■ **Procedure for gene drive inheritance:**

1. Follow the same procedure used in the normal inheritance case.
2. This time, if you choose the t allele and your partner draws a T, convert the T into a t.
3. Highlight the genotype of your offspring in the chart below. Note that it is not longer possible to have a heterozygous Tt in this new scenario.

■ **Genotype table:**

Genotype	Phenotype	Genotype	Phenotype
AA	2 antenna	Aa	1 antenna
aa	No antenna	mm	1 body hump
Mm	2 body humps	MM	3 body humps
QQ	Red nose	Qq	Orange nose
qq	Yellow nose	TT	Curly tail
tt	Straight tail	EE, Ee	2 eyes
ee	3 eyes	LL, Ll	Blue legs
ll	Red legs	DD, Dd	3 body segments
dd	2 body segments		

4. Determine the phenotypes of your offspring.
5. Build your offspring using the materials provided.

■ **Discuss:**

6. Compare your offspring with those from other pairs of parents.
7. How does this generation differ from the one created under normal inheritance?
8. Chart the number with curly tails versus straight tails across the entire class. How does it compare with the numbers under normal inheritance?
9. How do you expect the prevalence of curly tails to change in the coming generations?

Marshmallow inheritance

Directions: Prior to instruction, duplicate one set of cutouts on pink paper and one set on blue paper for each pair of students. Cut out shapes and place them into an envelope for each pair.

