

# Genetics - X-linkage

## Teacher's Guide

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### 1.0 Summary

The *X-Linkage Activity* is the sixth core Genetics activity. This activity is comprised of three sections and designed to last one class period of approximately 45-50 minutes.

### 2.0 Learning Goals

**Driving Question:** What difference does it make if a gene is part of the X Chromosome?

In *X-linkage* students investigate differences between autosomal and X-linked inheritance patterns using pedigree analysis.

*Part One: Introduction to Genes that are part of the X Chromosome* reviews how a gene is inherited when it is part of the X-chromosome.

*Part Two: X-Linked Traits* links the fire-breathing gene to the inheritance of the sex chromosomes through the generations.

*Part Three: Determining if a Characteristic is X-linked* focuses on pedigree analysis as a tool for discriminating between autosomal and X-linkage inheritance.

#### Learning Goals

- Students will understand what an autosomal trait is and on which chromosomes they are located.
- Students will understand what a sex-linked trait is and on which chromosome they are located.
- Students will know that egg cells contain only x chromosomes.
- Students will know that sperm cells contain either one X or one Y chromosome.
- Students will understand that Y-chromosomes are much smaller than X chromosomes and carry few genes.
- Students will use pedigree charts to identify traits.
- Students will identify traits as either being sex-linked or autosomal.
- Students will identify traits as being either dominant or recessive.
- Students will interpret these charts to determine that a trait is X-linked.
- Students will know that all X-linked alleles are expressed in males, even if they are recessive.

#### Additional Teacher Background

Sexually reproducing organisms have a pair of chromosomes known as sex chromosomes, which are called this primarily because they determine gender. In humans, the 23<sup>rd</sup> pair of chromosomes is composed of sex chromosomes.

Males have one X chromosome and one Y chromosome. Females have two X chromosomes and no Y chromosome. Because males have just one X chromosome, all X-linked alleles are expressed in males, even recessive alleles.

In determining human gender, all eggs carry a single X chromosome, while half of the sperm carry an X and the other half carry a Y. This means that the odds are approximately 50/50 of having either a boy or a girl when a sperm and an egg produce that offspring. That is of course without genetic intervention. It also means that a boy will inherit any genes that are part of that X chromosome. Over 100 genetic diseases have been discovered thus far on the X chromosome. Males are far more likely than females to evidence sex-linked traits; they only need one affected X chromosome. On the other hand, females can carry these genetic traits but rarely are afflicted; they need two copies of the diseased X chromosome in order to exhibit the trait.


### 3.0 Standards Alignment

#### Alignment to National Math and Science Standards (NCTM or NSES)

Objective	Standards
<b>Students will be able to distinguish between autosomal and sex-linked inheritance.</b>	Students will know that hereditary information is contained in genes, which are located in the chromosomes.
<b>Students will understand how x-linked genes are inherited.</b>	Students will know that heredity is the passage of instructions from one generation to another generation.
<b>Students will be able to determine through pedigree analysis whether a trait is X-linked or autosomal.</b>	The students will use representations to model and interpret physical, social, and mathematical phenomena.

## 4.0 Activity Sections

Welcome!




What difference does it make if a gene is part of the X Chromosome?

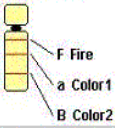
In X-linkage, you will learn about genes that are part of the sex chromosomes, the X Chromosome in particular. The sex chromosomes, otherwise known as the X and the Y Chromosomes, determine the gender of the offspring.

**Male**

Chromosome: Y

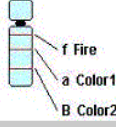


Chromosome: X

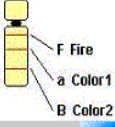


**Female**

Chromosome: X



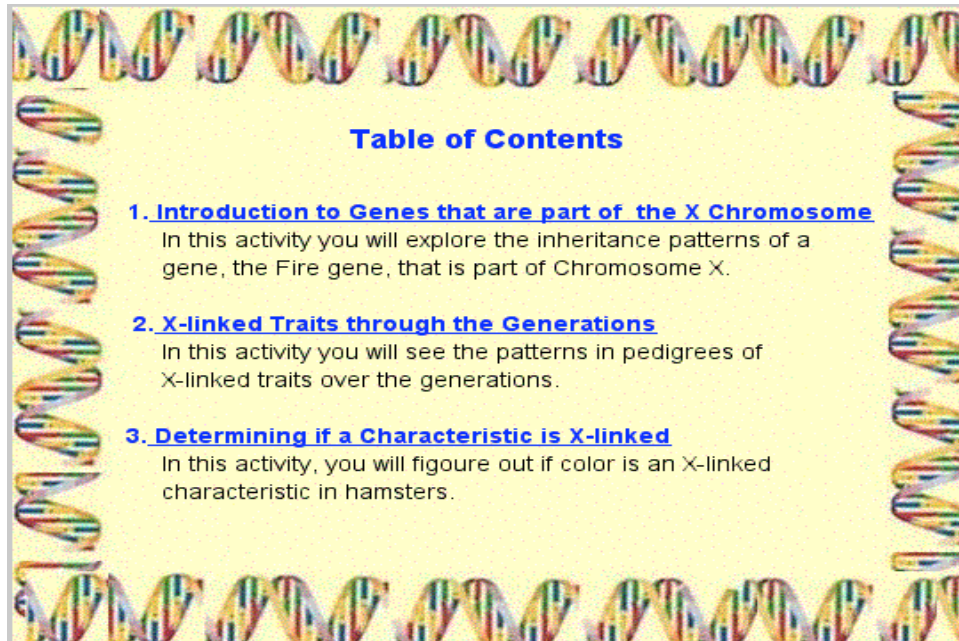
Chromosome: X



Opening Screen

### 4.1 Table of Contents

This activity has 3 sections: *Introduction to Genes that are part of the X Chromosome*, *X-Linked Traits* and *Determining if a Characteristic is X-linked*.



**Table of Contents**

- 1. Introduction to Genes that are part of the X Chromosome**  
In this activity you will explore the inheritance patterns of a gene, the Fire gene, that is part of Chromosome X.
- 2. X-linked Traits through the Generations**  
In this activity you will see the patterns in pedigrees of X-linked traits over the generations.
- 3. Determining if a Characteristic is X-linked**  
In this activity, you will figure out if color is an X-linked characteristic in hamsters.

**Table of Contents**

**4.2 1) Introduction to Genes that are part of the X Chromosome**

Step 1: Remember that the fire-breathing characteristic is part of the X chromosome. State the rule and determine which allele is responsible for fire breathing for a male. (The answer is f.)

Step 2: Experiment with the female chromosomes and determine which allele(s) are responsible for fire breathing for a female. (The answer is ff.)

Step 3: Answer the questions as you proceed through the screens. For questions 6 and 7, the answers are that the daughters of these offspring will not be fire breathers and that the sons will all be fire breathers.

Step 4: Review questions and summary.



**Note:** Refer to the Genome chart if you get stuck; it's icon is a sheet of note paper which is located in the lower left of the screen.

### Dragon Genome Chart

Having horns is dominant to no horns.

HH or Hh = horns                      hh = no horns

Having wings is recessive to no wings.

ww = wings                              WW or Ww = no wings

Legs are incompletely dominant.

ll = no legs                              Ll = 2 legs                      LL = 4 legs

Fancy Tails are dominant to plain tails.

TT or Tt = fancy tail                      tt = plain tail

Fire-breathing is recessive to non-fire-breathing and is an X-linked characteristic.

Males:                                      F- = non-fire-breathing males

f- = fire-breathing males


Females:                                    FF, Ff = non- fire-breathing females

ff = fire-breathing females


Color is a polygenic, X-linked characteristic.

Males:	Green	A-B-
	Yellow	a-B-
Females:	Red	AABB or AaBB
	Blue	aaBb
	Brown	AABb or AaBb
	Purple	aaBB

The Dragon Genome Chart is available at the click of a button.




**George**



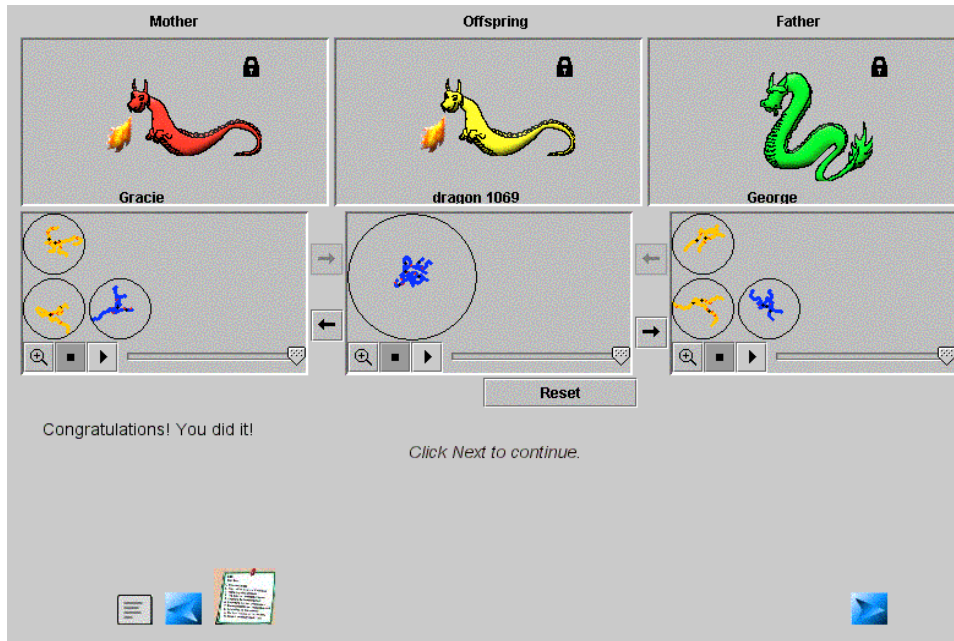
**Gracie**

1. How many fire-breathing alleles (f) does a female need to be fire-breathing?  
 0    1    2    3    4
2. How many does a male need?  
 0    1    2    3    4
3. What other gene(s) are part of the X chromosome but not the Y chromosome?  
 Horns    Wings    Legs    Tails    Color1    Color2



**Submit Answer**

Answer questions about the rule for Fire.



Create a fire breathing male dragon by using the meiosis model. Students must select gametes with f and - using the magnifying glass.

Fire Number of Offspring: 30

No Fire  Fire

10. Do you see a pattern here? Please describe the pattern.

All of the daughters are non-fire breathing while all of the males breath fire.

Submit Answer

Students breed George and Gracie to get an X-linked pedigree.

Complete this Punnett square so you can explain why the male offspring were fire-breathing and the female offspring were not.

We've filled in the alleles for George and Gracie. Note that George's Y chromosome is represented by a hyphen. That's because the Y chromosome doesn't have an allele for Fire.

Complete the Punnett square. Use a hyphen "-" to represent the Y chromosome when filling in the inner boxes.

**Submit Answer**

Students complete a Punnett square that explains the pedigree results.

Students then answer a series of questions about what they've done.

### 4.3 2) X- Linked Traits Through the Generations

In this section, students determine whether the offspring of a pair of dragons will be able to keep the family business (which requires some fire-breathers) going over several generations. They predict the traits of subsequent generations using rules for Fire, Pedigree Charts and Punnett Squares.

**X-Linked Traits Through the Generations**

No Fire     Fire

Gustav and Isabel are dragons planning to have a family. Isabel comes from a long line of guard dragons and would like her children and grandchildren to inherit the family business. However, the offspring that will inherit the business must breathe fire. Gustav (who can't breathe fire) and Isabel would like to know whether or not their sons and daughters might breathe fire and whether their granddaughters and grandsons might breathe fire. In this activity you will use the tools of BioLogica (and geneticists) to determine how likely it is they will be able to keep the family business going.

Students predict what the F1 generation will look like before crossing Isabelle and Gustav, shown above.

Isaiah

f      -

F      Ff      F-

f      ff      f-

Ophelia

We've placed Isaiah and Ophelia, parents from the F1 generation, in the Punnett square.

*Click on each of the dragons to check out their Fire alleles and complete the Punnett square.*

Submit Answer

They then complete a Punnett square to predict the F2 generation.

Fire

Number of Offspring: 60

No Fire     Fire

You said there would be . Compare the pedigree to your prediction.

Submit Answer

Then they produce the F2 generation, compare it with their predictions, and explain the results.



Isaiah

Ophelia

	f	-
F	Ff	F-
f	ff	f-

That's right! The box with 2 recessive Fire alleles (ff) corresponds to offspring that are female and fire-breathing. The box with one recessive fire allele and a hyphen (f-) corresponds to offspring that are male and fire-breathing.

22. What do you think the probability is that a particular FEMALE offspring from these parents will be fire-breathing? This is a tricky question so think carefully!

1/4  1/2  3/4

Submit Answer


Students work through a series of questions that link Punnett squares and probability and also ask for predictions and explanations.

#### 4.4 3) Determining if a characteristic is X-Linked


In this section, students investigate the inheritance of color among hamsters while the reasoning of a geneticist is modeled for them.

- Step 1: Answer a series of higher order questions based on knowledge gained in the preceding 2 sections.
- Step 2: Cross (remembering to use the X tool) parents to produce offspring.
- Step 3: Create Pedigree charts to determine if traits are dominant or recessive and autosomal or X-linked.
- Step 4: Create Punnett Squares to discover the same type of information sought in Step 3.
- Step 5: Practice Questions
- Step 6: Review and Summary

**Determining if a characteristic is X-linked**



**Goldie**



**Gregor**

Hamster breeders pay a lot of attention to the colors of their hamsters. Sometimes one color is very popular and then the fashion changes, so the breeders need to know as much as possible about Color genetics in hamsters. This activity is designed to help you prepare for your exam to become a hamster breeder.

Students act as hamster breeders.

Color 
Number of Offspring: 0

golden
  grey

● ■

Here are the same two hamsters in a pedigree. Goldie is a golden female and Gregor is a grey male. Notice that there is no Chromosome tool, so you'll have to figure out which Color is dominant, if Color is X-linked, and the parents' genotypes using only breeding experiments.

29. How would you determine which color is dominant? What would you look for?

Students are asked to describe how they will determine which color is dominant and whether color is sex-linked in hamsters.

Color Number of Offspring: 30

■ golden ■ grey

F1	Male	Female
Grey	7	6
Gold	4	13

32. Based on this pedigree and its data table, which color do you think is dominant?

Grey  Gold  Not sure

33. What is it about the F1 generation that makes you think so?

Students are given a data table at left as well as the pedigree and asked to interpret the data and justify their answer.

Color Number of Offspring: 30

■ golden ■ grey

Geneticists would look at this pedigree and notice that the colors are pretty evenly distributed among the offspring. That is, there are about equal numbers of grey and gold offspring and about equal numbers of males and females in each color. That doesn't really help answer any of our questions, so they would cross certain F1 generation hamsters.

*Cross a grey hamster with a grey hamster and a gold hamster with a gold hamster.*

The text explains how a geneticist would think about the data and the problem.

Color Number of Offspring: 90

■ golden ■ grey


Grey F2	Male	Female
Grey	16	14
Gold	0	0

Gold F2	Male	Female
Grey	5	0
Gold	6	19


34. Now which color do you think is dominant?  
 Grey  Gold  Not sure

35. Why do you think so?

The crosses that produced the F2 generation provide definitive data about dominance. If you cross two parents with the same trait and get some offspring with a different trait, then the parents have the dominant trait and the other trait is recessive.



Goldie



Gregor

To fill in a Punnett square you now need to figure out the parents' genotypes. You've already determined that gold is the dominant trait and grey is the recessive trait. For these purposes then G will represent the dominant [allele](#) and g will represent the recessive allele.

38. So, if Color in hamsters is [autosomal](#), what are the possible genotypes for GREY MALE hamsters?

Grey males:  GG  Gg  gg  G-  g-

A series of questions leads students through the reasoning needed to check their answers. It culminates in a comparison between a Punnett Square completed for an autosomal characteristic and a Punnett Square completed for an x-linked characteristic.

<table style="margin: auto;"> <tr> <td></td> <td style="border: 1px solid black; padding: 2px;">G</td> <td style="border: 1px solid black; padding: 2px;">g</td> </tr> <tr> <td style="border: 1px solid black; padding: 2px;">G</td> <td style="border: 1px solid black; padding: 2px;">GG</td> <td style="border: 1px solid black; padding: 2px;">Gg</td> </tr> <tr> <td style="border: 1px solid black; padding: 2px;">g</td> <td style="border: 1px solid black; padding: 2px;">Gg</td> <td style="border: 1px solid black; padding: 2px;">gg</td> </tr> </table> <p style="text-align: center;">Autosomal</p>		G	g	G	GG	Gg	g	Gg	gg	<table style="margin: auto;"> <tr> <td></td> <td style="border: 1px solid black; padding: 2px;">G</td> <td style="border: 1px solid black; padding: 2px;">-</td> </tr> <tr> <td style="border: 1px solid black; padding: 2px;">G</td> <td style="border: 1px solid black; padding: 2px;">GG</td> <td style="border: 1px solid black; padding: 2px;">G-</td> </tr> <tr> <td style="border: 1px solid black; padding: 2px;">g</td> <td style="border: 1px solid black; padding: 2px;">Gg</td> <td style="border: 1px solid black; padding: 2px;">g-</td> </tr> </table> <p style="text-align: center;">X-linked</p>		G	-	G	GG	G-	g	Gg	g-
	G	g																	
G	GG	Gg																	
g	Gg	gg																	
	G	-																	
G	GG	G-																	
g	Gg	g-																	

If you assumed that 1/2 of the offspring in each box of the Punnett square will be males, you could predict that about 1/8 of the offspring will be grey males. Otherwise, you can't really tell the probability of grey males in Punnett squares for autosomal characteristics.

In the X-linked Punnett square only one inner box (g-) corresponds to grey males; therefore it is likely that 1/4 of the offspring will be grey males and there will be no grey females.

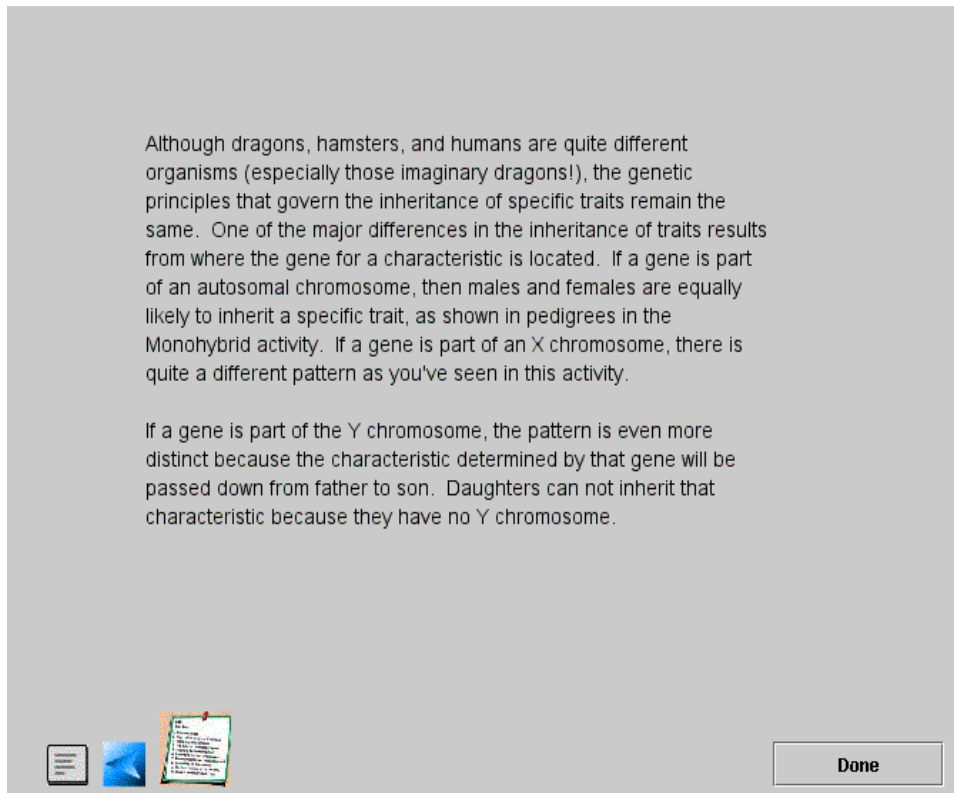
### Autosomal and X-Linked Punnett Squares

That's right.

Because sons get their X chromosome from their mothers, the only way a son can inherit the hemophilia allele is when one of the mother's X chromosomes has the recessive h allele that produces hemophilia. As you can see, in the Punnett square on the left the mother does not have an X chromosome with the recessive h allele. The father's X chromosome with the h allele is inherited by the daughters who can then pass it on to their sons. Since the mother on the right has an X chromosome with the h allele, she will pass it on to about half of her sons.

### Explanation of X-linked traits

A series of assessment questions, including questions about human color vision and hemophilia, concludes the section.



When students complete the assessment an explanation of Y linked traits is provided.

## 5.0 Student Reports

Your students' work with X-Linkage is logged and viewable on the MAC Project Web Portal at <http://mac.concord.org>. For each student, you can view a report containing questions and answers.

The next activity that students should use is *Mutations*, which focuses on the inheritance patterns for two traits at a time and the differences that occur when the genes for those traits are parts of the same chromosome or parts of different chromosomes.

*Mutations II*, an optional activity, can also be used after *X-Linkage*. *Mutations II* examines the inheritance patterns of new alleles created by mutations of chromosomes in the germ cells of organisms.