Chapter 7: Genes and Inheritance

Family resemblance: how traits are inherited

Lectures by Mark Manteuffel, St. Louis Community College
INHERITANCE OF GENES

Humans have 23 pairs of chromosomes (46 individual chromosomes) and, thus, two copies of each gene.

Each human gamete has just one copy of each chromosome and, thus, one copy of each gene.

Gametes unite during fertilization.

Child inherits one set of chromosomes from each parent and, thus, two copies of each gene.
Take-home message 7.1

- Offspring resemble their parents because they inherit genes from their parents.

- Genes are instruction sets for biochemical, physical, and behavioral traits.
7.2 Some traits are controlled by a single gene.

- **Heredity**
  - The passing of characteristics from parent to offspring through their genes
Traits that are determined by the instructions a person carries at one gene are called single-gene traits.

Figure 7-5
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Are there multiple-gene traits too?

- Yes

- Let us first examine the mechanism by which single-gene traits pass from parent to child.

- We will then expand this model of heritability.
Take-home message 7.2

- Many human traits are determined by instructions a person carries on a single gene, and these traits exhibit straightforward patterns of inheritance.
7.3 Mendel learned about heredity by conducting experiments.

MENDEL’S RESEARCH APPROACH

Three features of Mendel’s methodical research were critical to its success.

Gregor Mendel (1822–1884)

Figure 7-7
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True-Breeding

DOMINANT AND RECESSIVE TRAITS

Figure 7-8 part 1
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Take-home message 7.3

- In the mid-1800s, Gregor Mendel conducted studies that help us understand heredity.

- He focused on easily observed and categorized traits in garden peas and applied methodical experimentation and rigorous hypothesis testing to determine how traits are inherited.
Do Now:
Principle of Segregation:
You have two copies of each gene but you put only one copy in each sperm or egg.

Build a Punnet Square that shows the gametes of a Dominant Homozygous Long Haired Cat and a Recessive Homozygous Short haired cat.
A dominant trait masks the effect of a recessive trait.
MENDEL’S LAW OF SEGREGATION

According to Mendel’s law of segregation, only one of the two alleles for a gene is put into a gamete. At fertilization, offspring receive from each parent one allele for each gene.

Heterozygous pea plant  Heterozygous pea plant

Two different alleles (white, purple) for the same gene (flower color)

MEIOSIS Each gamete gets one copy of each gene.

FERTILIZATION Each fertilized egg gets two copies of each gene.

Homozygous recessive  Heterozygous  Heterozygous  Heterozygous  Homozygous dominant

Figure 7-9
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Take-home message 7.4

- Each parent puts a single set of instructions for a particular trait into every sperm or egg.
- The instruction set is called a gene.
- The trait observed in an individual depends on the two copies (alleles) of the gene it inherits from its parents.
7.5 Observing an individual’s phenotype is not sufficient for determining its genotype.
**Phenotype:** Little or no pigment in the eyes, hair, and skin

**Genotype:** Homozygous for the recessive allele for albinism
Phenotypes and Genotypes

- The outward appearance of an individual is called their **phenotype**.

- Underlying the phenotype is the **genotype**.
  - This is an organism’s genetic composition.
Genotypes

- Homozygous dominant
- Homozygous recessive
- Heterozygous
How do we analyze and predict the outcome of crosses?

- Assign symbols to represent the different variants of a gene.

- Generally, we use an uppercase letter for the dominant allele and lowercase for the recessive allele.
A Punnett square is a useful tool for determining the possible outcomes of a cross between two individuals.

**Cross 1**
- **Mother:** albino homozygous \( aa \)
- **Father:** pigmented homozygous \( AA \)

**GAMETES**
- \( A \)
- \( a \)

**OFFSPRING**
- Genotype: All heterozygous \( Aa \)
- Phenotype: All pigmented

**Cross 2**
- **Mother:** pigmented heterozygous \( Aa \)
- **Father:** pigmented heterozygous \( Aa \)

**GAMETES**
- \( A \)
- \( a \)

**OFFSPRING**
- Genotype: 
  - \( 1/4 \) homozygous dominant \( AA \)
  - \( 2/4 \) heterozygous \( Aa \)
  - \( 1/4 \) homozygous recessive \( aa \)
- Phenotype: 
  - \( 3/4 \) pigmented
  - \( 1/4 \) albino

Figure 7-11 part 1
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Figure 7-11 part 2
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Monohybrid Practice Problems / have students probability and what influenced that
Take-home message 7.5

- It is not always possible to determine an individual’s genotype from its phenotype.

- A recessive allele’s effects may be masked by a dominant allele.

- Genetic analysis makes use of clever experiments and Punnett squares.
7.6–7.8
Probability and chance play central roles in genetics.
Do Now

• What is the probability the offspring of the following crosses will be heterozygous?

1. Heterozygous orange cat crossed with a heterozygous orange cat

2. Homozygous black cat crossed with a heterozygous orange cat
7.6 Chance is important in genetics.

Probability has a central role in genetics for two reasons:

- The first is a consequence of segregation.
- The second reason is that fertilization, too, is a chance event.
Probabilities

- Any gamete produced by an individual heterozygous for a trait has a 50% probability of carrying the dominant allele and a 50% probability of carrying the recessive allele.
Probabilities

- If a male is heterozygous for albinism (Aa) and a female is homozygous for albinism (aa), what is the probability that their child will be homozygous for albinism (aa)?
**GENETICS AND PROBABILITY**

*IF...*

The mother is albino, and the father is heterozygous.

*THEN...*

There is a 100% chance that the mother’s egg will carry the recessive $a$ allele and a 50% chance that a sperm will carry the recessive $a$ allele.

*AND...*

0.5 or 50% chance the offspring will be albino.

Multiply the two components together to determine the overall probability.

Figure 7-12

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Dihybrid crosses

- Examining probabilities of the inheritance of two traits.
Do Now

• What is the ratio observed in the heterozygous cross of the Cyclops insects?

• What is the ratio of possible offspring for the following problem:
  Heterozygous long haired orange cat X homozygous short haired black cat
  
  – Step 1: Determine all 4 possible gametes for each cat.
    • Hint – remember each gamete must have one allele for each trait.
  – Step 2: Fill each square with the possible result of fertilization between the two gametes.
Mendel’s Law of Independent Assortment

- Genes tend to behave independently.
- The inheritance pattern of one trait doesn’t usually influence the inheritance of any other trait.
Three Ideas Mendel Used for Explaining This Pattern of Inheritance

1. Each parent puts into every sperm or egg it makes a **single set** of instructions for building the trait.
Three Ideas Mendel Used for Explaining This Pattern of Inheritance

2. Offspring thus find themselves with two copies of the instructions for any trait (called alleles).
Three Ideas Mendel Used for Explaining This Pattern of Inheritance

3. The actual trait produced by an individual depends on the *two* copies of the gene that they inherit from their parents.
Take-home message 7.6

- Chance plays a role in fertilization too.

- All of an individual’s sperm or eggs are different.

- Any of these gametes may be the gamete involved in fertilization.
7.7 A test-cross enables us to figure out which alleles an individual carries.
You would like to produce white alligators via a mating program.
The problem is that you cannot be certain of the genotype of your alligators.
They might be homozygous dominant, $MM$, or they might be heterozygous, $Mm$.

In either case, their phenotype is normal coloration.

How can you figure out which of these two possibilities is the actual genotype?
**TEST-CROSS: WHITE ALLIGATORS**

- **Mother**: White homozygous (mm)

- **Father**: Pigmented, unknown genotype (MM or Mm)

  **Gametes**: m, m

**Unknown allele could be M or m.**

**Offspring (if unknown genotype is MM)**

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>All heterozygous Mm</td>
<td>All pigmented</td>
</tr>
</tbody>
</table>

**Offspring (if unknown genotype is Mm)**

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/4 heterozygous Mm</td>
<td>2/4 pigmented</td>
</tr>
<tr>
<td>2/4 homozygous recessive mm</td>
<td>2/4 white</td>
</tr>
</tbody>
</table>

**Figure 7-14 part 2**

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Take-home message 7.7

- In a test-cross, an individual with a dominant phenotype and an unknown genotype is mated with a homozygous recessive individual.

- The phenotypes of the offspring reveal the unknown genotype.
Using pedigrees to decipher and predict the inheritance patterns of genes.

*Pedigree:* A type of family tree
Analyzing Which Individuals Manifest the Trait and Which Do Not

A pedigree is a useful tool to document a trait of interest across multiple generations of family members.

- Grandfather
- Grandmother
- Grandfather
- Grandmother
- Aunt
- Uncle
- First cousin
- Aunt
- Uncle
- First cousin
- Father
- Mother
- Uncle
- Aunt

- Female exhibiting trait of interest
- Female not exhibiting trait
- Male exhibiting trait of interest
- Male not exhibiting trait
Sex-Linked Traits

A pedigree is a useful tool to document a trait of interest across multiple generations of family members.

Grandfather  Grandmother  Grandfather  Grandmother

Aunt  Uncle  Father  Mother  Uncle  Aunt

First cousin  First cousin  Sister  Me  Sister

- Female exhibiting trait of interest
- Female not exhibiting trait
- Male exhibiting trait of interest
- Male not exhibiting trait
Genes that are located on the X chromosome are called sex-linked genes.

Traits determined by sex-linked genes are called sex-linked traits

Ex. Color blindness

female $X^c X^c$

male $X^c Y$
Most Sex linked traits are recessive, this means both x chromosomes must have the gene in order for the trait to be expressed.

If only one x chromosome is present (in males) and has the sex linked gene, then the trait will be expressed, women need to have two copies.
Carriers

• A carrier is a person that has the trait on only one chromosome and does not express the trait. Carriers of sex linked traits are always women.

  (C= normal, c= colorblind)

Ex. Color blind carrier  \( X^C X^c \)
A colorblind male marries a normal female. What are the offspring genotypes and phenotypes?

<table>
<thead>
<tr>
<th></th>
<th>X&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>X&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X<sup>c</sup> - Colorblind; Y - Normal
A normal male (not colorblind) marries a colorblind female. What are the offspring genotypes and phenotypes?
Anury is a condition in dogs and other animals in which they are born without a tail. The condition is inherited as a recessive trait.

**IF...**
A dog has no tail, but both parents do (such as individual “3”).

**THEN...**
We know with certainty each parent’s genotype. (Can you figure out the genotypes of 1 and 2?)

This puppy definitely inherits a recessive allele from its father. It will have anury if (1) its mother has a recessive allele and (2) she passes that allele to the puppy. What is that probability?
Practice Problems
A Trait’s Mode of Inheritance Is Not Always Completely Obvious

- Complete dominance or...

- The influence of the environment (such as temperature)

Siamese cats have a temperature-sensitive pigmentation gene. In cooler areas of a cat's body (nose and paws), this gene is expressed to a greater degree.
In arctic fox, the brown summer fur turns to white as temperatures drop.

As temperatures drop, melanin genes are turned off, or the enzymes that catalyze the production of melanin change shape and no longer function. The result is that no melanin is produced, and thus the fur turns white.
7.9 Incomplete dominance and codominance: The effects of both alleles in a genotype can show up in the phenotype.
Incomplete dominance, in which the heterozygote appears to be intermediate between the two homozygotes.

**Incomplete dominance occurs when a heterozygote exhibits an intermediate phenotype between the two homozygotes.**

**INCOMPLETE DOMINANCE: SNAPDRAGONS**

The superscript W represents the allele that produces a white flower. (The alternative allele has a superscript R, representing the allele that produces a red flower.)

**Cross 1**
- **Father**: Red-flower homozygous $C^R C^R$
- **Mother**: White-flower homozygous $C^W C^W$
- **GAMETES**: $C^W, C^R$
- **Offspring**: All heterozygous $C^W C^R$
  - **Phenotype**: All pink flowers

**Cross 2**
- **Father**: Pink-flower heterozygous $C^W C^R$
- **Mother**: Pink-flower heterozygous $C^W C^R$
- **GAMETES**: $C^W, C^R$
- **Offspring**:
  - 1/4 homozygous $C^R C^R$
  - 1/4 heterozygous $C^W C^R$
  - 1/4 homozygous $C^W C^W$
  - 1/4 red flowers
  - 2/4 pink flowers
  - 1/4 white flowers

*Figure 7-17
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Hair Type

- Straight Hair: Homozygous: Incomplete Dominant
- Curly Hair: Homozygous: Incomplete Dominant
- Wavy Hair: Heterozygous: A mix (Straight and Curly)
**Codominance**, in which the heterozygote displays characteristics of both homozygotes.
Take-home message 7.9

- Sometimes, the effects of both alleles in a heterozygous genotype are visible.

- Incomplete dominance—a heterozygote displays a characteristic somewhere between the characteristics of the two homozygotes.

- Codominance—a heterozygote displays characteristics of both homozygotes.
7.10 What’s your blood type?

Some genes may have more than two alleles.
Multiple Allelism

- A single gene has more than two alleles.
- Each individual still carries only two alleles.
Inheritance of the ABO Blood Groups

- A, B, and O alleles

- The A and B alleles are both completely dominant to O.

- The A and B alleles are codominant to each other.

- Individuals can be one of four different blood types: A, B, AB, or O.
Multiple allelism occurs when there are three or more alleles for a gene within a population. An individual still inherits only two alleles—one from each parent.

Three alleles possible:
- A (dominant to O and codominant with B)
- B (dominant to O and codominant with A)
- O (recessive to A and B)

Red blood cells have 6 different genotypes (AA, AO, BB, BO, AB, and OO). These genotypes result in 4 different phenotypes (type A, type B, type AB, and type O).

Figure 7-19
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**BLOOD TYPE, ANTIGENS, AND ANTIBODIES**

**ANTIGENS**
Chemicals on the surface of some cells. They act as signposts that tell the immune system whether the cell belongs in the body.

**ANTIBODIES**
Immune system molecules that attack cells with foreign antigens.

**TYPE A**
- A antigens
- B antibodies

**TYPE B**
- B antigens
- A antibodies

**TYPE AB**
- A and B antigens
- Neither A nor B antibodies

**TYPE O**
- Neither A nor B antigens
- A and B antibodies

Individuals produce antibodies to the antigens they don’t have on their cells.

*Figure 7-20*
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Why are people with **type O** blood considered “universal donors”? Why are those with **type AB** considered “universal acceptors”?

<table>
<thead>
<tr>
<th>BLOOD TYPE</th>
<th>CAN DONATE TO</th>
<th>CAN RECEIVE FROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Type A, Type AB</td>
<td>Type A, Type O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type B</td>
<td>Type B, Type AB</td>
<td>Type B, Type O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type AB</td>
<td>Type AB</td>
<td>Type A, Type B, Type AB, Type O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type O</td>
<td>Type A, Type B, Type AB, Type O</td>
<td>Type O</td>
</tr>
</tbody>
</table>

**Figure 7-21**

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*Individuals with type O blood are universal donors. Individuals with type AB are universal recipients.*
Take-home message 7.10

- In multiple allelism, a single gene has more than two alleles.

- Each individual still only carries two alleles, but more alleles occur in the population.

- This is the case for the ABO blood groups in humans.
7.13 Why are more men than women color-blind?

*Sex-linked traits differ in their patterns of expression in males and females.*
If a man is color-blind, did he inherit this condition from his mother, his father, or both parents?
SEX-LINKED TRAITS: COLOR-BLINDNESS

A sex-linked trait is carried on the X chromosome. Women carry two copies of the X chromosome, while men carry an X chromosome and a Y chromosome.

Gene with instructions for light-sensitive proteins within the eye

Two alleles possible:
- \( R \) (produces functioning light-sensitive proteins)
- \( r \) (produces defective light-sensitive proteins)

TO BE COLOR-BLIND

Male must inherit color-blindness allele \((r)\) from his mother.

Female must inherit color-blindness allele \((r)\) from both parents.

TO HAVE NORMAL VISION

Male must inherit normal color-vision allele \((R)\) from his mother.

Female can inherit normal color-vision allele \((R)\) from either her mother or her father.

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Take-home message 7.13

- The patterns of inheritance of most traits do not differ between males and females.

- When a trait is coded for by a gene on a sex chromosome, such as color vision on the X chromosome, the effects differ in males and females.
7.16 Red hair and freckles

*Genes on the same chromosome are sometimes inherited together.*
Why do most redheads have pale skin?

Linked genes: Genes on the same chromosome, maybe even right next to each other
LINKED GENES

If this gamete is fertilized, the linked genes will be passed on to the offspring together as a group.

If genes are far apart on a chromosome or are on different chromosomes, the inheritance of one does not influence the inheritance of another.

Figure 7-29
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Take-home message 7.16

- Sometimes, having one trait, such as red hair, influences the presence of another trait, pale skin.

- This is because the alleles for two genes are inherited and expressed together when they are close together on the same chromosome.