7.6: Genetic Variation

What helps ensure the survival of a species?

Genetic variation. It is this variation that is the essence of evolution. Without genetic differences among individuals, "survival of the fittest" would not be likely. Either all survive, or all perish.

Genetic Variation

Sexual reproduction results in infinite possibilities of genetic variation. In other words, sexual reproduction results in offspring that are genetically unique. They differ from both parents and also from each other. This occurs for a number of reasons.
• When homologous chromosomes form pairs during prophase I of meiosis I, crossing-over can occur. **Crossing-over** is the exchange of genetic material between homologous chromosomes. It results in new combinations of genes on each chromosome.

• When cells divide during meiosis, homologous chromosomes are randomly distributed to daughter cells, and different chromosomes segregate independently of each other. This is called **independent assortment**. It results in gametes that have unique combinations of chromosomes.

• In sexual reproduction, two gametes unite to produce an offspring. But which two of the millions of possible gametes will it be? This is likely to be a matter of chance. It is obviously another source of genetic variation in offspring. This is known as **random fertilization**.

All of these mechanisms working together result in an amazing amount of potential variation. Each human couple, for example, has the potential to produce more than 64 trillion genetically unique children. No wonder we are all different!

**Crossing-Over**

Crossing-over occurs during prophase I, and it is the exchange of genetic material between non-sister chromatids of homologous chromosomes. Recall during prophase I, homologous chromosomes line up in pairs, gene-for-gene down their entire length, forming a configuration with four chromatids, known as a **tetrad**. At this point, the chromatids are very close to each other and some material from two chromatids switch chromosomes, that is, the material breaks off and reattaches at the same position on the homologous chromosome (Figure \(\PageIndex{2}\)). This exchange of genetic material can happen many times within the same pair of homologous chromosomes, creating unique combinations of genes. This process is also known as **recombination**.

![Crossing-over](https://bio.libretexts.org/Bookshelves/Human_Biology/Book%3A_Human_Biology_(Wakim_and_Grewal)/07%3A_Cell_Repro...)

During prophase I, chromosomes condense and become visible inside the nucleus. As the nuclear envelope begins to break down, homologous chromosomes move closer together. The synaptonemal complex, a lattice of proteins between the homologous chromosomes, forms at specific locations, spreading to cover the entire length of the chromosomes. The tight pairing of the homologous chromosomes is called synapsis. In synapsis, the genes on the chromatids of the homologous chromosomes are aligned with each other. The synaptonemal complex also supports the exchange of chromosomal segments between non-sister homologous chromatids in a process called crossing over. The crossover events are the first source of genetic variation produced by meiosis. A single crossover event between homologous non-
sister chromatids leads to an exchange of DNA between chromosomes. Following crossover, the synaptonemal complex breaks down and the cohesin connection between homologous pairs is also removed. At the end of prophase I, the pairs are held together only at the chiasmata; they are called tetrads because the four sister chromatids of each pair of homologous chromosomes are now visible.

Figure \(\PageIndex{3}\): Crossover between homologous chromosomes Crossover occurs between non-sister chromatids of homologous chromosomes. The result is an exchange of genetic material between homologous chromosomes. This occurs when homologous chromosomes align. Chromatids from each chromosome can cross over and recombine (swap sections). This results in two recombinant chromosomes and two non-recombinant chromosomes.

**Independent Assortment and Random Fertilization**

During metaphase I, the tetrads move to the metaphase plate with kinetochores facing opposite poles. The homologous pairs orient themselves randomly at the equator. This event is the second mechanism that introduces variation into the gametes or spores. In each cell that undergoes meiosis, the arrangement of the tetrads is different. The number of variations is dependent on the number of chromosomes making up a set. There are two possibilities for orientation at the metaphase plate. The possible number of alignments, therefore, equals \(2^n\), where \(n\) is the number of chromosomes per set. Given these two mechanisms, it is highly unlikely that any two haploid cells resulting from meiosis will have the same genetic composition.

Figure \(\PageIndex{4}\): Meiosis I ensures unique gametes Random, independent assortment during metaphase I can be demonstrated by considering a cell with a set of two chromosomes \((n = 2)\). In this case, there are two possible
arrangements at the equatorial plane in metaphase I. The total possible number of different gametes is \(2n\), where \(n\) equals the number of chromosomes in a set. In this example, there are four possible genetic combinations for the gametes. With \(n = 23\) in human cells, there are over 8 million possible combinations of paternal and maternal chromosomes.

In humans, there are over 8 million configurations in which the chromosomes can line up during metaphase I of meiosis. It is the specific process of meiosis, resulting in four unique haploid cells, that results in these many combinations. This independent assortment, in which the chromosome inherited from either the father or mother can sort into any gamete, produces the potential for tremendous genetic variation. Together with random fertilization, more possibilities for genetic variation exist between any two people than the number of individuals alive today. Sexual reproduction is the random fertilization of a gamete from the female using a gamete from the male. A sperm cell, with over 8 million chromosome combinations, fertilizes an egg cell, which also has over 8 million chromosome combinations. That is over 64 trillion unique combinations, not counting the unique combinations produced by crossing-over.

**Review**

1. What is crossing-over and when does it occur?
2. Describe how crossing-over, independent assortment, and random fertilization lead to genetic variation.
3. How many combinations of chromosomes are possible from sexual reproduction in humans?
4. Create a diagram to show how crossing-over occurs and how it creates new gene combinations on each chromosome.

**Explore More**

[https://bio.libretexts.org/link?16758#Explore_More](https://bio.libretexts.org/link?16758#Explore_More)

**Attributions**

1. [Supplier Diversity Strategies](https://profilesindiversityjournal.org/) by Profiles in Diversity Journal, [CC BY 3.0](https://creativecommons.org/licenses/by/3.0) via Wikimedia Commons
2. [Chromosomal Recombination](https://openstax.org/) by David Eccles (Gringer), licensed [CC BY 2.5](https://creativecommons.org/licenses/by/2.5) via Wikimedia Commons
3. [Crossing over](https://openstax.org/) by OpenStax, licensed [CC BY 4.0](https://creativecommons.org/licenses/by/4.0)
4. [Independent assortment](https://openstax.org/) by OpenStax, licensed [CC BY 4.0](https://creativecommons.org/licenses/by/4.0)
5. Text adapted from [Human Biology](https://openstax.org/) by CK-12 licensed [CC BY-NC 3.0](https://creativecommons.org/licenses/by-nc/3.0)