Genetic Variation - Advanced

Douglas Wilkin, Ph.D.
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Learning Objectives

• Explain why and how sexual reproduction leads to variation in offspring.

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. Everyone would be exactly the same. How would it be determined who could or would survive? Either all survive, or all perish.

Meiosis and 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 through a number of mechanisms, including crossing-over, the independent assortment of chromosomes during anaphase I, and random fertilization.

• When homologous chromosomes form pairs during prophase I of meiosis I, crossing-over can occur. Crossing-over is the exchange of genetic material between non-sister chromatids of homologous chromosomes. It results in new combinations of genes on each chromosome.
• When cells divide during meiosis, homologous chromosomes are randomly distributed during anaphase I, separating and segregating 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**

As mentioned above, 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**. The process of pairing the homologous chromosomes is called **synapsis**. During synapsis, non-sister chromatids may cross-over at points called **chiasmata**. Within a **chiasma**, the genetic material from two non-sister chromatids actually intertwine around each other, and some material from non-sister chromatids switch chromosomes, that is, the material breaks off and reattaches at the same position on the homologous chromosome (**Figure 1.1**). This exchange of genetic material can happen many times within the same pair of homologous chromosomes, creating unique combinations of alleles. This process is also known as **homologous recombination**.

**FIGURE 1.1**

During crossing-over, segments of DNA are exchanged between non-sister chromatids of homologous chromosomes. Notice how this can result in an allele (A) on one chromosome being moved to the other chromosome. The four chromatids compose the tetrad, with a chiasma at the point of exchange.

**MEDIA**

Click image to the left or use the URL below.

**URL**: http://www.ck12.org/flx/render/embeddedobject/184637
Independent Assortment and Random Fertilization

In humans, there are over 8 million configurations in which the chromosomes can line up during metaphase I of meiosis. It is the specific processes of meiosis, resulting in four unique haploid cells, that result 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. This process underlies the chromosomal basis of inheritance. Gregor Mendel’s findings and laws will be discussed in the Inheritance concepts, but essentially, his findings led to the development of two laws of inheritance: the Law of Segregation and the Law of Independent Assortment. The Law of Segregation states that when any individual produces gametes, the copies of a gene separate so that each gamete receives only one copy (one allele) of that gene. The Law of Independent Assortment states that separate genes for separate traits are passed independently of one another from parents to offspring.

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. In humans, over 8 million (2^{23}) chromosome combinations exist in the production of gametes in both the male and female. Essentially, when the homologous pairs of chromosomes line up during metaphase I and then are separated at anaphase I, there are (2^{23}) possible combinations of maternal and paternal chromosomes. During random fertilization, a sperm cell, with over 8 million possible chromosome combinations, fertilizes an egg cell, which also has over 8 million possible chromosome combinations. Together, there are over 64 trillion unique combinations, not counting the additional variation produced by crossing-over during prophase I. In other words, each human couple could produce a child with over 64 trillion unique chromosome combinations!

Mitosis vs. Meiosis

Mitosis and meiosis are two types of cell division, with dramatically different products. Mitosis begins with a diploid somatic cell and ends with two genetically identical diploid cells. Meiosis begins with a diploid cell and produces four haploid genetically unique cells that form gametes.

<table>
<thead>
<tr>
<th></th>
<th>cells</th>
<th>starting cell</th>
<th>cell division</th>
<th>ending cells</th>
<th>when</th>
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<td>Mitosis</td>
<td>somatic cells</td>
<td>one diploid cell</td>
<td>one round</td>
<td>two genetically identical diploid cells</td>
<td>occurs during the cell cycle</td>
</tr>
<tr>
<td>Meiosis</td>
<td>gamete producing cells</td>
<td>one diploid cell</td>
<td>two rounds</td>
<td>four genetically unique haploid cells</td>
<td>occurs during the production of gametes</td>
</tr>
</tbody>
</table>
FIGURE 1.2
Mitosis vs. Meiosis Comparison. Mitosis produces two diploid daughter cells, genetically identical to the parent cell. Meiosis produces four haploid daughter cells, each genetically unique.

Summary

- Crossing-over, the independent assortment of chromosomes during anaphase I, and random fertilization all increase the genetic variation of a species.

Review

1. Define crossing-over in meiosis.
2. Describe how crossing-over, independent assortment, and random fertilization lead to genetic variation.
3. Describe how independent assortment relates to the laws of inheritance.
4. Define chiasmata.
5. When does mitosis and meiosis occur?

References