3D MEIOTIC DIVISION
A LEARNING EXPERIENCE IN AUGMENTED REALITY

ACTIVITY GUIDE

LIITEC
LABORATORIO DE INVESTIGACIÓN E INNOVACIÓN TECNOLÓGICA PARA LA EDUCACIÓN EN CIENCIAS

UNIVERSIDAD DE LA SERENA CHILE

V 1.01

It is currently known that meiotic cell division, or meiosis, is one of the main sources of genetic variation in sexually reproducing eukaryotic organisms. During the second half of the 19th century, several researchers attempted to explain this observed variability and its association with changes at the cellular level.

In 1876, the German zoologist Oskar Hetwig proved that fertilization occurs due to the fusion of the nuclei of a sperm and an egg cell. Later, between 1883 and 1887, the Belgian biologist Edouart van Beneden described the cell division process, which he termed meiosis (from the Greek term for 'lessening'), after studying gametogenesis in the parasite Ascaris. He observed that meiosis consists of two successive cell divisions that produce cells with half the typical number of chromosomes for a given species.

In 1900, when Mendel's work was rediscovered, the relationship between chromosomes and the principles of inheritance (genes) proposed by Mendel was still unclear. In that same year, Walter Sutton, a biologist at Columbia University, showed, after a careful study of meiosis in insects, that this process was the biological basis for the principles of inheritance proposed by Mendel. Around that same period, the German cytologist Theodor Bovery arrived at the same conclusions.

Sutton knew that cells had two pairs of chromosomes (diploid), each chromosome having a matching pair – its homologous chromosome. In each pair of homologous chromosomes, one chromosome is inherited from the father and one from the mother.

As previously mentioned, meiosis occurs only in sexually reproducing organisms. It takes place in gonads as part of the gametogenesis processes (spermatogenesis and oogenesis) that lead to the formation of gametes, egg cells and sperm cells.

Meiosis involves two successive cell divisions, but only one round of DNA replication, that result in a reduction to half the number of original chromosomes. Consequently, gametes receive only half the number of chromosomes compared to the other cells in the organism. While the behavior of chromosomes during meiosis is fundamentally the same in different species, the process differs in timing and duration. The type of meiosis observed in higher plants and animals is called 'terminal' or 'gametic' because meiotic divisions take place immediately before gametes are formed.

During meiosis, the first round of cell division is reductionist and preceded by DNA replication, whereas the second round is similar to mitosis, i.e., it is equational and not preceded by DNA synthesis. The cell division process that occurs during meiosis I and II is continuous, but it is typically divided into the following distinct stages:

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PRIMERA DIVISIÓN MEIÓTICA

Prophase I

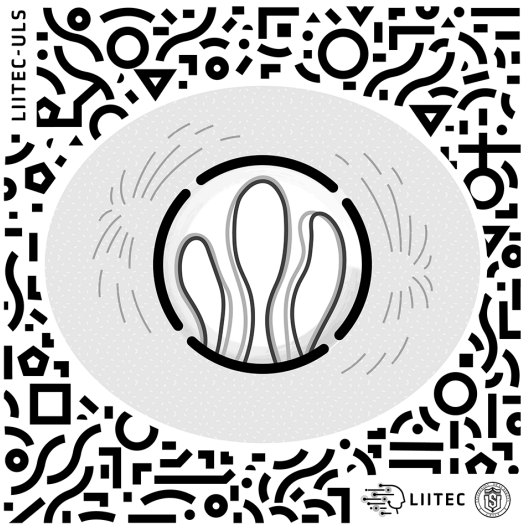
It is the longest stage and is preceded by an interphase characterized by DNA replication. It is subdivided into five stages based on the behavior of chromosomes.

Leptotene

During this stage, chromatin fibers condense to form chromosomes which appear as thin filaments within the nucleus that are connected to the internal face of the nuclear envelope. These chromosomes are made up of two chromatids and a centromere.

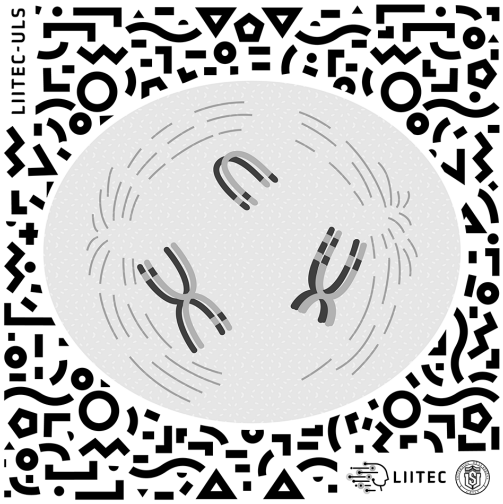
Zygotene

In this stage, the duplicated homologous chromosomes begin to pair (synapse) from their ends, or telomeres. In between both duplicated chromatin fibers a protein structure known as synaptonemal complex begins to develop. This structure is responsible for the fusion and pairing of duplicated homologous chromosomes. This pairing is completed in the next phase, known as pachytene (not shown here). The duplicated, paired homologous chromosomes form a bivalent, or tetrad, made up of four chromatids. During this stage, the paired homologous chromosomes exchange genetic material in a process called crossing-over.



Diplotene

Once the pachytene stage (not shown here) is completed, and after crossover takes place, the paired homologous chromosomes begin to separate, except in the regions where crossover has occurred. These points of contact are known as chiasmata. A chiasma is the cytological manifestation of the genetic phenomenon known as crossing-over.

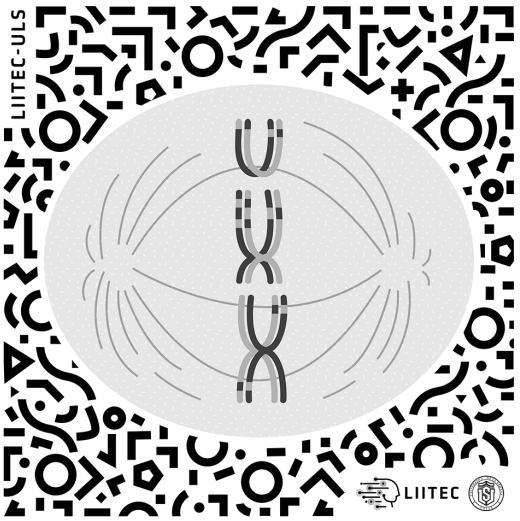


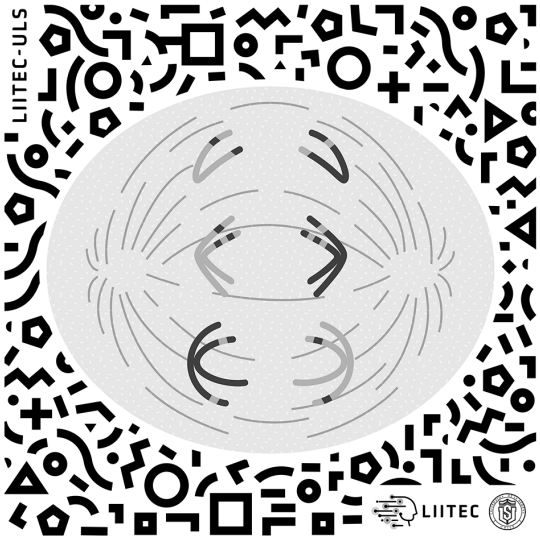
Diakinesis

The paired homologous chromosomes remain partially held together at chiasmata that move towards the ends of the chromosomes, the nuclear membrane disintegrates, and the meiotic spindle of meiosis I begins to form.

Metaphase I

During this stage, the bivalents, or tetrads, line up on the cell's equatorial plane. The microtubules originating in one pole attach to one of the chromosomes in each homologous pair, whereas the microtubules originating on the other pole attach to the other member in each pair. The alignment of the different bivalents on the equatorial plane occurs at random – a phenomenon known as chromosomal permutation – and results in different combinations of maternal and paternal chromosomes. The number of possible combinations is 2n, where n is the number of homologous chromosome pairs. In humans, which have 23 pairs of chromosomes, a total of 8,388,608 possible combinations of chromosomes can result from the random separation of homologous chromosomes.



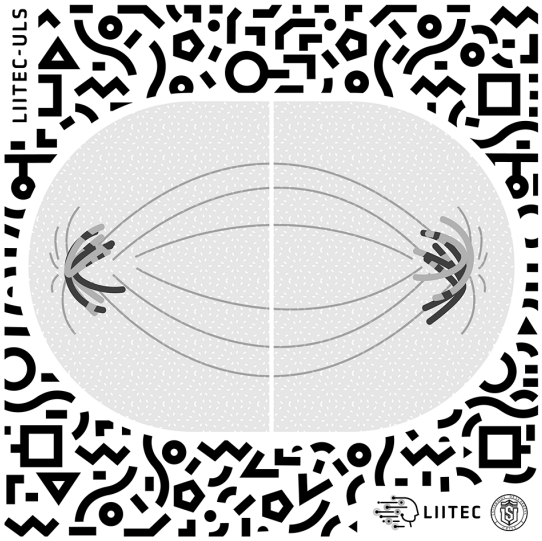


Anaphase I

At this stage, the homologous chromosomes separate and start to migrate toward opposite poles of the cell, resulting in two cells with half the number of chromosomes, i.e., haploid. However, since each chromosome is made up of two chromatids, the DNA content is still 2c.

Telophase I

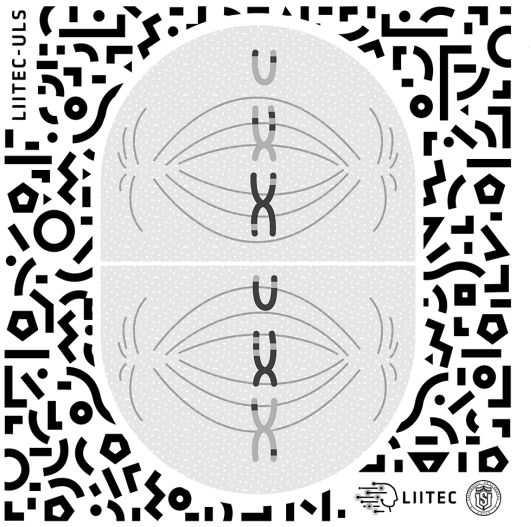
At this stage, chromosomes reach opposite poles, spindle microtubules slide apart, the nuclear envelope forms, and chromosomes become visible as thin threads as a result of decondensation. Simultaneously, cytokinesis (division of cytoplasm) occurs, resulting in two daughter cells with a haploid number of chromosomes (n), but 2c of DNA.

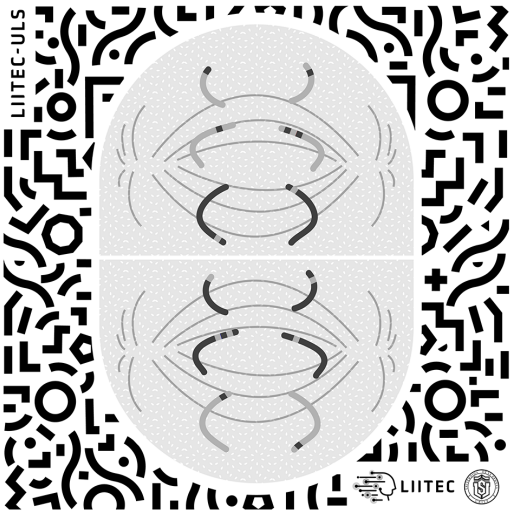


MEIOSIS II

Metaphase II

This stage is preceded by a very short prophase II in which the nuclear envelope breaks down and the spindle fibers form. The chromosomes, made up of two chromatids and one centromere, line up in the equatorial plane with the meiotic spindle microtubules attached to the kinetochores in the centromere of each chromosome.



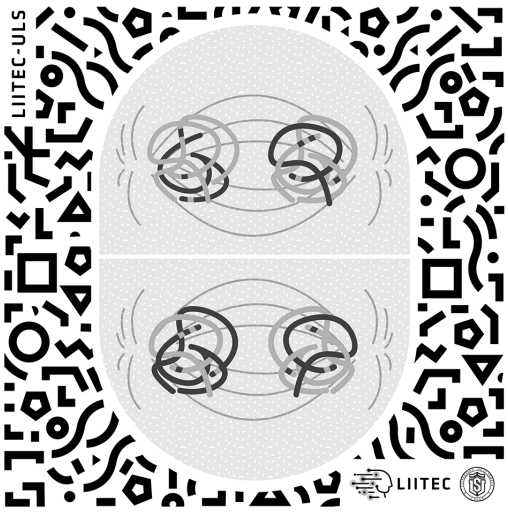


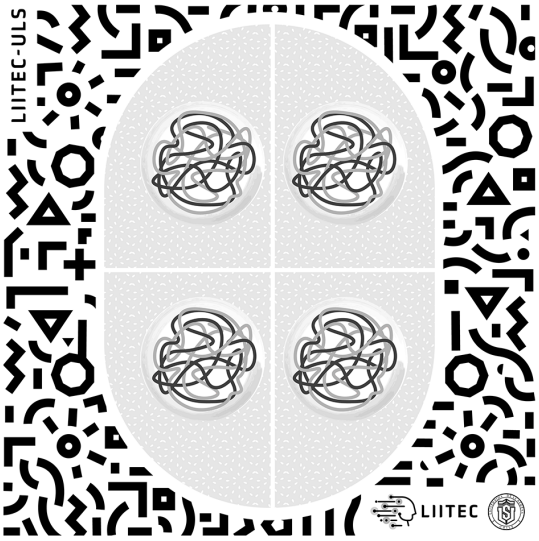
Anaphase II

The traction exerted by the spindle microtubules causes the sister chromatids to separate and migrate to their respective poles.

Telophase II

At this stage, the corresponding number of chromosomes for the given species reach opposite poles and a nuclear envelope forms around each set of chromosomes. Then, chromosomes begin to decondense and cytokinesis occurs, resulting in four cells with half the number of chromosomes (haploid) and DNA content.





Quartet

Chromosome decondensation is completed and the nucleus and nuclear envelope are formed. Cytokinesis produces 4 daughter cells containing half the number of chromosomes (haploid) and nuclear DNA content.

ASSESS WHAT YOU HAVE LEARNED FROM THIS EXPERIENCE

1.- What difference can you observe between metaphase I and metaphase II chromosomes?

2.- Based on what you observed in this app, what is the number of chromosomes that each cell will have at the end of this cell division?

3.- In the app, the cell undergoing meiosis has three pairs of homologous chromosomes. Based on the chromosome permutation phenomenon in metaphase I, how many possible combinations of maternal and paternal chromosomes may result?

4.- If we assume that the initial cell presented in the app contains 12 picograms of DNA

How many picograms of DNA would be present in the cell during prophase I?

How many picograms of DNA would be present in the cell during metaphase I?

How many picograms of DNA would be present in the cell at the end of telophase I?

How many picograms of DNA would be present in the cell during metaphase II?

How many picograms of DNA will be present in the cells resulting from this division process?

5.- If some drug were used to prevent the migration of chromosomes in one of the cells entering anaphase II, what is the number of chromosomes that would be present in the cells resulting from this division?