# An Interactive Introduction to Organismal and Molecular Biology, 2nd ed.

An Interactive Introduction to Organismal and Molecular Biology, 2nd ed.

ANDREA BIEREMA

SARA MILLER

Michigan State University Libraries East Lansing



An Interactive Introduction to Organismal and Molecular Biology, 2nd ed. Copyright © 2021 by Andrea M.-K. Bierema is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License, except where otherwise noted.

# Contents

# UNIT I. ORGANISMAL BIOLOGY

1. Reproduction Andrea Bierema 9

**UNIT I** 

# ORGANISMAL BIOLOGY

#### ANDREA BIEREMA

# CHAPTER 1

# Reproduction

#### ANDREA BIEREMA

Learning Objectives

Students will be able to:

- Define and identify examples of sexual and asexual reproduction.
- Explain how cell division is a part of reproduction.
- Describe and identify from real photos what happens to chromosomes during mitosis and meiosis.
- Define and identify sex cells.
- Define fertilization.
- Distinguish between chromatid replicates and chromosome pairs.

Note on Sex and Gender

9

This chapter highlights topics regarding reproduction and sex and does not refer to gender, which is a different concept.

*Sex* refers to a set of biological attributes in humans and animals. It is primarily associated with physical and physiological features including chromosomes, gene expression, hormone levels and function, and reproductive/sexual anatomy. Sex is usually categorized as female or male but there is variation in the biological attributes that comprise sex and how those attributes are expressed.

Gender refers to the socially constructed roles, behaviors, expressions, and identities of girls, women, boys, men, and genderdiverse people. It influences how people perceive themselves and each other, how they act and interact, and the distribution of power and resources in society. Gender identity is not confined to a binary (girl/woman, boy/man) nor is it static; it exists along a continuum and can change over time. There is considerable diversity in how individuals and groups understand, experience, and express gender through their roles, the expectations placed on them, relations with others, and the complex ways that gender is institutionalized in society.

## SEXUAL AND ASEXUAL REPRODUCTION

Reproduction is the production of offspring. This can happen in a variety of ways and is usually separated into sexual and asexual reproduction.

*Sexual reproduction*: Reproduction giving rise to offspring that have genetically unique combinations of genes (involves meiosis, a cell division process that creates sex cells).

*Asexual reproduction*: Reproduction that results in offspring that is genetically identical to the reproducing individual. Note that this is a different term than human asexual identity.



# CELL DIVISION

Reproduction requires cell division- either for creating sex cells (for sexual reproduction) or the reproduction itself (asexual reproduction). Cell division is when one cell divides into two- as the image below illustrates. But, what happens in the cell during cell division?



Scanning electron microscope image of Lytechinus pictus [sea urchin] embryo entering the 2-cell stage.

# **DNA Replication**

As a cell prepares for division, some of the organelles duplicateoften by dividing. One of the key processes that need to happen is for the DNA to duplicate, or as it is often referred to, replicate. What would happen if the DNA did not duplicate before cell division? Recall from an earlier chapter that every DNA molecule contains genes. If all of these genes were not replicated, then only some of them would go to one cell and others to another cell and the cell would not have the complete map to create the proteins it needs to survive and function.

田

One or more interactive elements has been excluded from this version of the text. You can view them online here: https://openbooks.lib.msu.edu/isb202/?p=335#oembed-1

# Chromosomes

See the chapter Gene Expression Overview to review the content on eukaryotic DNA and chromosomes. Below is a graphic that shows how DNA is packaged into a chromosome.



The organization of a **eukaryotic** chromosome starts with the DNA and zooms out to the chromosome. A double-stranded DNA molecule wraps around histone proteins to form nucleosomes that create the appearance of "beads on a string." The nucleosomes are coiled into a 30-nm chromatin fiber. the chromatin further condenses into what is called a chromosome. When a cell prepares for division, the chromosomes condense even further.

After DNA replicates, it condenses into visible (under a microscope,

that is) chromosomes. The original molecule and its replicate bind together forming one chromosome that is composed of two chromatids.



# **Types of Cell Division**

After the DNA is replicated, the cell finishes preparing for division (e.g., proteins needed for division are synthesized). Cell division results in new cells. During binary fission and mitosis, it results in two identical cells that are also identical to the parent cells. Meiosis, on the other hand, results in four unique cells.

# **Binary Fission and Mitosis**

*Binary fission* is a form of reproduction that produces two unicellular offspring that are identical to each other and the parent cell. When the parent cell has a nucleus (and therefore, cell division includes the division of a nucleus), it is called *mitosis*.

*Note*: The term "binary fission" can be confusing. Often, it is used to explain asexual reproduction in bacteria and other organisms that do not have a nucleus. However, the term is sometimes used to explain reproduction in unicellular organisms that do have a nucleus (e.g., unicellular algae) and even some multicellular plants. In these cases, the full phrase is "binary fission by mitosis." Additionally, some organisms reproduce via "multiple fission by mitosis," such as amoeba. Confusing, right? For our purposes, we will use "binary fission" to describe asexual reproduction without mitosis, which occurs in bacteria and other organisms that do not contain a



The rest of this section will focus on eukaryotic cells (i.e., cells with a nucleus and more than one chromosome), which divide via mitosis. Mitosis occurs for three main reasons:

- Asexual reproduction: creates two identical, unicellular offspring
- Growth: a multicellular organism produces more cells as it grows
- Repair: old cells are replaced via the division of live cells

The main processes that occur in mitosis are that the chromosomes (those with two identical chromatids- the original and replicate DNA molecules) line up in the middle of the cell and the chromatids are pulled apart from one another by spindles and move to opposite sides of the cell. Once this happens, the same DNA exists in both halves of the cell and the cell can divide into two.

The video below illustrates what this separation of paired chromatids looks like.

An interactive H5P element has been excluded from this version of the text. You can view it online here: https://openbooks.lib.msu.edu/isb202/?p=335#h5p-145

The next video (Inoue, Bajer, and Mole-Bajer, 2011) illustrates what happens to the chromatids; the spindle fibers are not visible. The video begins right after the DNA condenses into chromatids after DNA replication. It illustrates the chromatids continuing to condense and gradually travel to the center of the cell. Once in the center (halfway through the video), it almost looks like the chromosomes duplicate, but it is actually just the chromatids separating from one another. Once they separate, a cell membrane begins to form in the middle and the chromatids become less condensed and, therefore, more difficult to see. A nuclear envelope/membrane forms around the genetic material on each side.



One or more interactive elements has been excluded



## Meiosis

Unlike binary fission and mitosis, meiosis includes two rounds of cell division and produces four, unique cells. This *process creates sex cells* (or in the case of plants, the precursors of sex cells).

There are two main events that occur during meiosis:

1. The *separation of chromosomes* that have *similar* genetic information.

# 2. The separation of identical chromatids (similar to mitosis).

Most organisms that reproduce sexually have two sets of every gene- albeit, different variations of these genes. This is because they receive genetic material from two parents. Because genes are located on chromosomes, the chromosomes of these offspring can be paired according to the genes located on them.



An organized representation of human chromosomes. The number of chromosome pairs varies species-to-species; humans have 23 pairs. For each chromosome pair, one chromosome came from the female parent and the other from the male parent. Each pair of chromosomes contains different variations of the same genes. The exception is the X/Y, which are the sex chromosomes.

Before meiosis begins, the chromosomes with the same genes pair up. These chromosome pairs will be separated into different cells during the first cell division of meiosis.



3D image of pairing chromosomes in preparation for meiosis. Proteins that aid in pairing are illuminated in this image, which line along every chromosome.

Under the microscope, the separation of the chromosome pairs looks similar to separating identical chromatids. During this first division of meiosis, rather than *chromosomes* forming a single line that then divides into separate chromatids, the *chromosome pairs* line up and the pairs are separated from each other.

The video (Oldenbourg and LaFountain , 2010) below begins with the chromosome pairs lined up in the middle of the cell and then they are separated by spindle fibers. These cells are from an insect spermatocyte.



Chromosome Recombination Increases Genetic Diversity

Before meiosis officially begins, not only does the DNA replicate,

creating chromatid replicates that bind together, recombination occurs. Recombination introduces new gene combinations into populations by "crossing" over chromosomes of the same pair. That is, once the chromosomes find their matched pairs, they exchange some DNA with each other. The exchange is variants of the same genes- so offspring still receive the full instructions to produce it. Because of this shuffling, genes from the parent's female parent and genes from the parent's male parent can wind up next to one another on the same stretch of DNA. *This is why meiosis produces four unique cells- not two sets of two unique cells.* 



This graphic illustrates chromosome recombination (also called "crossing over." The red chromosomes are from one parent and the blue chromosomes are from the other parent. As the cell prepares for meiosis, the chromosome pairs come together, and parts of the chromatids from one parent exchange with the other parent. This is illustrated in the second image with chromosomes of different colors overlapping and then in the third image by showing chromosomes of different colors. Note that in this situation, "parent" refers to the parents of the individual that is producing the sex cells- it is not fertilization.



# SEX CELLS

Most sexually reproducing species have two sex cell types that differ in size: egg and sperm. Eggs and sperm for each species are identified by the size of the sex cell rather than the characteristics of the individual possessing the sex cells: egg cells are larger than sperm cells. The difference in size is due to how the cytoplasm- the material in the cell- in a cell divides. For sperm cells, during meiosis, the cytoplasm divides evenly across the four cells. For egg cells, most of the cytoplasm goes into one cell; the other three that are produced via meiosis cannot be fertilized.



Sperm fertilizing an egg. The large sphere is the egg and the thin fiber with a head going across it horizontally is the sperm. Notice the difference in size between these two sex cells.

Some individuals only produce one type of sex cell (identified as males or females) while others may produce both sperm and eggs. Those that produce both types are called hermaphrodites- either sequential (they can switch from producing one sex to producing another sex cell) or simultaneous they can produce both sex cells at one time).

# FERTILIZATION AND EARLY EMBRYONIC DEVELOPMENT

In sexually reproducing species, two sex cells- that are two different types, such as sperm and egg- combine to produce a single cell (called a zygote) with a nucleus.



Human fertilization: an egg cell surrounded by a few sperm cells.

In most animals and other multicellular organisms, fertilization is followed by mitosis for growth. The following video (Inoue, Sardet, and Speksnijder, 2011) illustrates fertilization and early embryonic development.



#### Exercise



# ATTRIBUTIONS

This chapter is a modified derivative of the following sources:

Canadian Institutes of Health Research. (2020). What is gender? What is sex? This text is a modified derivative of the version available on the *CIHR website*.

Understanding Evolution. University of California Museum of Paleontology. "Sex and genetic shuffling: The details." 10 August 2021 http://evolution.berkeley.edu/evolibrary/news/ 060101\_batsars

Webster, A., Zemenick, A., & Jones, S. (n.d.). Inclusive and accurate approaches for teaching sex and gender in biology. From *Biodiversify* https://projectbiodiversify.org/definitions/

# VIDEOS

Rudolf Oldenbourg, James R. LaFountain (2010) CIL:9064, *Nephrotoma suturalis*, spermatocyte. CIL. Dataset. https://doi.org/doi:10.7295/ W9CIL9064 Public domain. Shinya Inoue, A.S. Bajer, J. Mole-Bajer (2011) CIL:11952, *Haemanthus katharinae*, endosperm. CIL. Dataset. https://doi.org/ doi:10.7295/W9CIL11952 CC BY-NC-SA.

Shinya Inoue, Lionel Jaffe, Christian Sardet, Johanna Speksnijder (2011) CIL:11962, Phallusia mammilata, egg. CIL. Dataset. https://doi.org/doi:10.7295/W9CIL11962 CC BY-NC-SA.

Thomas Maresca, Edward Salmon (2011) CIL:26271, Drosophila melanogaster. CIL. Dataset. https://doi.org/doi:10.7295/ W9CIL26271 Public domain