YEAR 11
BIOLOGY
PATTERNS IN NATURE
LESSON 1: CELL THEORY
1. **What is Cell Theory?**

☐ **Introduction**

- There are many different **levels of organisation** in biology.
  - Cell theory refers to the level of the **individual cell** and is the idea that the cell is the **fundamental unit of life**.

- **Watch this VIDEO** (Length 6:12) from TEDEducation about Cell Theory as a helpful introduction to the lesson.

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<tr>
<th>PRINCIPLE</th>
<th>CLASSICAL</th>
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<tr>
<td>All organisms are made up of one or more cells.</td>
<td>✓</td>
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<tr>
<td>Cells are the fundamental unit of life.</td>
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<td>All cells come from pre-existing cells.</td>
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<td>Energy flow occurs within cells.</td>
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<td>Cells contain hereditary information that is passed from cell to cell during cell division.</td>
<td>✗</td>
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<td>All basic chemical and physiological processes are carried out inside cells.</td>
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<td>All cells are basically the same in chemical composition.</td>
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<tr>
<td>Cell activity depends upon the activities of sub-cellular structures within the cell.</td>
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<tr>
<td>All known living things are made up of cells.</td>
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- A cell originates from the **division** of another cell.
- The structure and function of a new cell is governed by **DNA**.
- Cells undergo **chemical** and **physiological processes** such as respiration, photosynthesis and glycolysis (as we will look at in more detail later on).
- Cells contain sub-cellular structures called **organelles** that are responsible for its maintenance, growth and function.
**Concept Check 1.1**

(a) Name the organism with only one cell.¹

(b) Name the organism with two or more cells.²

(c) What is the name given to the hereditary information contained in cells?³

(d) What are some examples of chemical or physiological processes?⁴

(e) What is the name given to sub-cellular structures in cells?⁵

(f) What are some examples of sub-cellular structures?⁶
2. **History of Cell Theory**

Students learn to
- Outline the historical development of the cell theory, in particular, the contributions of Robert Hooke and Robert Brown.
- Describe evidence to support the cell theory.

**Important events in the Development of Cell Theory**

- The development of classical cell theory occurred over a period of around 600 years as the technology of lenses and microscopes improved.
  - The invention of the microscope allowed the first glimpses of microscopic life.

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Major events in cell biology & imaging

- Robert Hooke observes cells of a cork tree through a primitive microscope.
- Leewenhoek discovers bacteria.
- Leewenhoek discovers protozoa.
- Schleiden & Schwann propose the Cell Theory.
- Golgi stains cells with silver nitrate, discovering the Golgi apparatus.
- Sheep "cloned" in 1997.
- Ruska builds the first transmission electron microscope.
- Kolliker describes mitochondria in muscle.
- 1st commercial scanning electron microscope.
- Koch uses aniline dyes to identify bacteria causing TB and cholera.
1280: Alessandro della Spina Invents Spectacles

- In 1280, Alessandro della Spina invented the first magnifying glass, known as spectacles.

- He began developing spectacles after injuring his eyes.
  - He found using quartz convex lenses improved his sight by magnifying images.

Concept Check 2.1

Why was the invention of spectacles by Alessandro della Spina important in the development of cell theory?
1590: Hans and Zacharias Janssen Invents the Compound Microscope

In 1590, Hans and Zacharias Janssen continued to develop the art of lenses.
- They found that placing lenses at opposite ends of a tube improved magnification.
- They invented the compound microscope with a magnification of 3X to 9X.

Concept Check 2.2
What did the Janssens invent and how did this invention contribute to the development of cell theory?
- 1609: Galileo Galilei Develops Convex and Concave Lenses
  - Galileo vastly improved the designs of convex and concave lenses.
    - He was able to combine them to get a much higher magnification than anything else available in his day.

- 1665: Robert Hooke Observes Cork Cells
  - Scientists were utilising microscopes to research matter unseeable to the 'naked eye'.
  - In 1665, Robert Hooke placed a thin slice of cork under a compound microscope.
    - He observed the cork's structure as 'filled with air and that air is perfectly enclosed in little boxes or cells distinct from one another'.
    - So, Hooke coined the term 'cells' – why cells? The boxes reminded him of the rooms in monasteries in which monks used to live! His illustration is below.
Nowadays, it is known that Hooke observed the **cellular layout** of **plant cell** divided by cell walls.

**Concept Check 2.3**

(a) How was Hooke limited in his observations of cells under the microscope?⁹

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(b) Describe the contributions Hooke made to cell theory.¹⁰

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1676: Anton van Leeuwenhoek Observes ‘Animalcules’

- Later in 1676, Anton van Leeuwenhoek, an untrained scientist, continued to utilise microscopes.
  - He was actually a Dutch merchant who used ‘microscopes’ to examine the quality of linen cloth and later turned his microscope on all sorts of thing from the natural world.

- He improved and produced high quality microscopes that were small (two inches by one inch) but very powerful (25x to 275x magnification).

- Using this microscope he entered the world of microscopic life that was unknown to humans at the time.
- He observed motile particles. He assumed that motility equated to life and went on to conclude, in a letter of 9 October 1676 to the Royal Society that these particles were indeed living organisms.
- He named them "animalcules".
- Nowadays, they are called protozoa and other unicellular organism.
- This opened the eyes of scientists at the time and often his work was criticised.
One of the many things Leeuwonhoek was the first to observe and record were sperm (from various organisms), as picture in his drawing below.

Watch a VIDEO (Length 2:27) about Leeuwenhoek and his amazing microscope. It's quite interesting to see how it works!

Concept Check 2.4
Anton van Leeuwenhoek observed ‘animalcules’ under the microscope. How did his observations contribute to cell theory? 

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1824: Henri Dutrochet Suggests all Organisms are Composed of Cells

- Up to 1824, Leeuwenhoek and Hooke’s work was followed by Henri Dutrochet, as he repeated the observation of ‘animalcules’ (or microorganisms) in stagnant water.

- Dutrochet played an important role in developing cell theory as, unlike his predecessors and his contemporaries, he did not regard living matter as either a variant of froth or as a uniform and compact matter crisscrossed by various pipes and channels and holed with cavities, but rather as made up of individual cells.
  - His theory conflicted with that of Spontaneous Generation, which stated that life spontaneously originates from non-living matter and NOT from another living cell, as known nowadays.

- In further experiments, he was able to confirm that both plants and animals were made up of cells – albeit slightly different in structure.
1827: Robert Brown Named and Described the Nucleus

- The fascination of the cell continued to fascinate scientists and this provided means to accelerate **microscopic observational technology**.

- In 1827, Scottish botanist Robert Brown named the **nucleus** in plant cells.
  - The word ‘nucleus’ actually means ‘little nut’ in Latin.

- The nucleus had probably been observed earlier by Leeuwenhoek and Franz Bauer (Bauer drew it as a regular feature in plant cells).
  - However, neither Brown nor Bauer thought that it was a universal feature of cells.
  - In fact, Brown thought it was confined to monocotyledons (flowering plants with one embryonic leaf in their seeds).
Concept Check 2.5

(a) Describe the contributions of Robert Brown to the development of cell theory.\(^{12}\)

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(b) In what way were Brown's ideas incorrect, in regards to cells?\(^{13}\)

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1838: Schleiden and Schwann Formulated Cell Theory

Prior to 1838-1839, scientists were sceptical about a possible theory behind cells. Now, cells were beginning to be seen as separate components within organisms.

- Some cellular components, such as the nucleus, had been visualized, and the occurrence of these structures in cells of different tissues and organisms hinted at the possibility that **cells of similar organisation might underlie all living matter**.

Therefore, in 1838, **Mattias Jakob Schleiden** and **Theodor Schwann** put forward an outline for **cell theory**.

**Schleiden** was a lawyer turned botanist who studied plant structure under the microscope.

- He, along with Schwann, recognised that different parts of plants were made up of cells.
- He also recognised the importance of the **nucleus** and its connection with **cell division**.

**Schwann** was a German zoologist who, after discussing nuclei in plants with Schleiden, recognised that **animals** too were made up of cells and wrote a paper (Microscopic Investigations on the Accordance in the Structure and Growth of Plants and Animals) in which he stated that “**all living things are composed of cells and cell products.**”

Although Schleiden and Schwann articulated the cell theory, they were confused about the **origin** of cells, thinking that they arose from crystallisation of intercellular substances.
This was not the first time that scientists had stated that all organisms were made of cells, but the research of Schleiden and Schwann provided increasing amounts of evidence for the theory.

- From this time on, scientists regarded cells as the building blocks of life.

Concept Check 2.6

(a) Outline the ideas proposed in classical cell theory.\textsuperscript{14}

(b) What incorrect assumption did Schwann and Schleiden make about the origin of cells?\textsuperscript{15}
1859: Rudolph Virchow Identifies How New Cells are Made

In 1859, further evidence was provided by a German physician and biologist Rudolph Virchow, who stated that “every cell originates from another pre-existing cell like it”.

- This was an important step in the development of cell theory as it rejected the commonly held belief of spontaneous generation.
- What is spontaneous generation?¹⁶

Virchow recognised that all cells divide and this was how new cells were made.
- What is the name given to the process of cell division?¹⁷
1879: Walther Flemming Describes Mitosis

- Walther Flemming was a German histology lecturer, with a particular talent for drawing.

- At the beginning of his career, Flemming was interested in mollusc sensory organs and the behaviour of individual cells and was heavily influenced by his teachers, Virchow and Max Schultze, to view the cell as the fundamental unit of life.

- By the time Flemming began looking at cell division however other scientists had already observed this phenomenon and partially described it (e.g. Anton Schneider in 1873).

- Flemming however, added more depth to the descriptions and in places corrected assumptions about mitotic division.
  - E.g. where Schneider suggested the cell nucleus undergoes cell deformation during division, Flemming identified that it actually transformed into ‘threads’.
  - What is the name given to the threads in the nucleus? \(^{18}\)
By looking at various wounds and scars, Flemming and his students came to the realisation that **regeneration** of cells, tissues and organs comes about through **cell division**.

Flemming was **limited** by **technology** of the time.
- Many of his hypotheses (e.g. that nucleus threads move due to spindle fibres) could not be proven as the microscopes could not produce high quality images – light intensity was poor (as it often depended upon sunlight) and condenser systems were rudimentary (so pseudo-phase-contrast of subjects could not be achieved).

You may work through this **ANIMATION** to get a better idea of Flemming’s work and contribution to Cell Theory.

**Concept Check 2.7**

(a) Scientists before Flemming had previously observed mitosis under the microscope. In what way was Flemming’s contribution significant to the development of cell theory?^{19}

(b) How was Flemming limited in his development of cell theory?^{20}
1933: Ernst Ruska Builds the First Electron Microscope

- Ernst Ruska was a German physicist who thought that microscopes using electrons would render a more detailed image than microscopes that used light.
  - Electrons have wavelengths around 1000 times shorter than light, and up until this point, magnification in microscopy had been limited by the size of light wavelengths.

- Experimenting with different lenses and focal lengths, Ruska built the first electron microscope with Dr Knoll in 1931 but demonstrated its use in 1933 – with an electron microscope he had built by himself.

- Electron microscopes have been monumental in developing our understanding of the cellular world.
  - However, their one large drawback is that specimens must be dead, preserved, and mounted properly before they are viewed.
  - This somewhat limits the ability to understand cellular processes as they happen in real time.
Concept Check 2.8

(a) State the classical cell theory.21

(b) What ideas were added to classical cell theory, in order to define modern cell theory?22

(c) Identify the invention of Ernst Ruska that contributed to the development of modern cell theory and explain why this development was necessary for cell theory.23
3. Technology and Cell Theory

Students learn to
- Discuss the significance of technological advances to developments in the cell theory.
- Use available evidence to assess the impact of technology, including the development of the microscope, on the development of the cell theory.

Development of the Microscope

- The development of the cell theory would not have been possible without the microscope.
  - This technology allowed scientists to observe cells and their overall structure as well as explore the inner space of cells and their subcellular structures.
  - Other advances however, such as slide preparation and advanced staining techniques, also aided the development of cell theory.

The Light Microscope

- The compound light microscope is a commonly used tool in biology.
- Despite the fact that more powerful electron microscopes have been developed to view specimens, the light microscope is still used due to its versatility and general ease of use.

![Diagram of a microscope]

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A) Base  
B) Arm  
C) Fine focus  
D) Coarse focus  
E) Body tube  
F) Rotating nosepiece  
G) Low power objective (4x)  
H) High power objective (100x)  
I) Mid-power objective (40x)  
J) Stage  
K) Iris diaphragm  
L) Stage clips  
M) Light source  
N) Ocular lens
New Dyes for Use as Stains

- Dyes tend to be specific so you need to use the right one to **highlight** what you want to look at!

- Some **examples** of stains include:
  - Methylene blue (blue): used to highlight nuclei;
  - Crystal violet (purple): used to stain cell walls when mixed with a moderant to fix the dye to the cell wall;
  - Haematoxylin (blue): used to stain chromosomes to show mitosis/meiosis; and
  - Rhodamine (purple/red): a fluorescent pigment used to stain proteins.

![Methylene Blue Stain](image1)

![Rhodamine Stain](image2)
New Illumination Sources

- Confocal laser scanning microscopy uses lasers to illuminate a specimen.
  - A series of images can be stored on a computer using this technology and can be altered to produce a 3D image of the specimen.
  - Below is a 3D image (and the sections that make it up) produced using confocal laser scanning microscopy.

Source: http://www.mih.unibas.ch/Booklet/Booklet96/Chapter1/Chapter1.html

- Magnifications of up to 3000 times are possible using lasers!
Improved Phase Contrast of Specimens

- **Phase contrast** is based on the ability of light waves to increase their amplitude when they are in phase or cancel out when they are out of phase.
  - A ring inserted into the condenser of the light microscope produces dark areas in the final image where light waves are out of phase and bright areas when in phase.
  - **Light** and **dark areas** are produced because different areas of the specimen retard light by different degrees so that it is in or out of phase.

![Positive Phase Contrast](image1)

![Negative Phase Contrast](image2)
Concept Check 3.1

(a) Describe two technological advances in light microscopy that have enabled the continued use of the compound light microscope.\(^{24}\)

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(b) For one of the advances described in part (b), explain how this enabled the development of modern cell theory.\(^{25}\)

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ANSWERS

1. Unicellular.
3. DNA.
4. Photosynthesis, respiration etc.
5. Organelles.
6. Nucleus, ribosome, endoplasmic reticulum.
7. It provided the beginnings under which improved lenses and microscopes could be produced therefore allowing the study of microscopic life.
8. Janssen invented the first compound microscope. This contributed to cell theory as improvements to magnification brought scientists one step closer to studying microscopic life.
9. Hooke was limited by technology – the level of magnification was limited therefore he was only able to observe plant cells.
10. Hooke was the first scientist to observe cells under a microscope. This initial discovery of cells assisted in the development of cell theory.
11. Leeuwenhoek was the first to view live cells under a microscope, discovering unicellular ‘animalcules’. This confirmed the existence of cells other than the plant cells within Hooke’s thin slice of cork.
12. Brown was the first to identify the nucleus in plant cells, thus increasing the understanding of cells and their constituents.
13. Brown did not know that the nucleus was a universal feature of both plant and animal cells.
14. Ideas in classical cell theory:
   - All organisms are made up of one or more cells.
   - Cells are the fundamental unit of life.
   - All cells come from pre-existing cells.
15. Schleiden and Schwann were incorrect about the origin of cells, thinking that they arose from crystallisation of intercellular substances.
16. A theory stating that life spontaneously originates from non-living matter and NOT from another living cell.
17. Mitosis.
18. Chromosomes.
19. Flemming added more depth to the descriptions of mitosis and in places corrected assumptions about mitotic division. As such, he increased the understanding of how cells arise from pre-existing cells which is instrumental to the development of cell theory.
20. Flemming was limited by technology of the time – many of his hypotheses could not be proven as the microscopes could not produce high quality images. E.g. light intensity was poor (as it often depended upon sunlight) and condenser systems were rudimentary (so pseudo-phase-contrast of subjects could not be achieved).
21. All organisms are made up of one or more cells. Cells are the fundamental unit of life. All cells come from pre-existing cells.
22. Energy flows within cells. Cells contain hereditary information that is passed from cell to cell during cell division. All basic chemical and physiological processes are carried out inside cells. All cells are basically the same in chemical composition. Cell activity depends upon the activities of sub-cellular structures within the cell. All known living things are made up of cells.
23. Ernst Ruska developed the electron microscope which has a significantly higher level of magnification and resolution than a conventional compound light microscope. This was essential for the development of the modern cell theory because it allowed for cells to be viewed in more detail i.e. for the observation of smaller organelles. As such, chemical and physiological processes carried out by smaller organelles/sub-structures could be observed and understood.
24. Improvement in staining techniques used in conjunction with the compound light microscope has allowed scientists to view different parts of the cell more clearly. Improvements in lighting techniques for the compound light microscope such as phase contrast of specimens have improved the quality of images obtained.
25. Improvement in staining techniques using different coloured dyes that are taken up by different parts of the cell have allowed scientists to clearly view the sub-cellular structures of the cell. As such, this allows for observation of cell activities as well as chemical and physiological processes carried out by these organelles, thus providing evidence to support cell theory.