Subject Code	BIO 1	Biology 1
Lesson Guide Code	1.0	The Eukaryotes
Lesson Code	1.2	Evolution of Multicellular Organisms
Time Frame		30 minutes

TARGET

After completing this learning guide, you are expected to:

- describe how multicellular forms may have evolved from protists, and
- evaluate the advantages and disadvantages of multicellularity.

HOOK

There are many species that are unicellular and there are also many species that are multicellular and possess cells that are of different types. How did multicellular cells evolve? Think of magnetic balls that are rolling individually on a table; suddenly they get close to each other and their magnetic force pulls them all together to become one unit. For unicellular cells, was the force that made them evolve to multicellularity akin to that of a magnetic force? What factor drove organisms to become multicellular? Why did we not stay as one big giant cell?

IGNITE

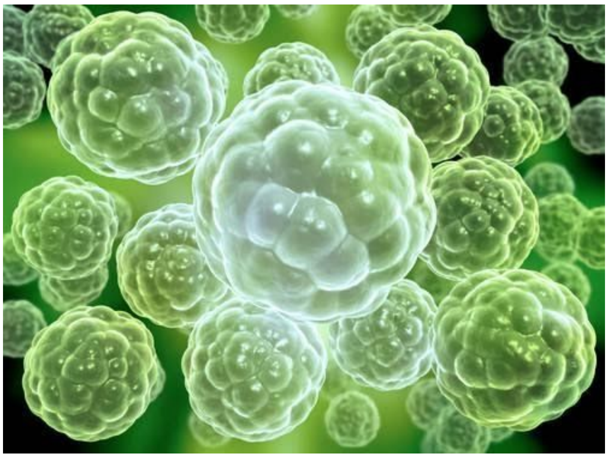
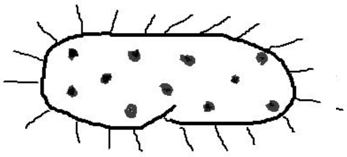


Figure 1. Evolution of multicellular life, from *Multicellular organism* by Wilkin and Akre (2020), https://www.ck12.org/biology/multicellular-organism/lesson/the-evolution-of-multicellular-life-advanced-bio-adv/. License: CC BY-NC 3.0

Multicellularity refers to the condition wherein an organism has more than one cell and has specialized cells grouped together to perform different functions. The evolution of organisms to multicellularity is said to have happened many times. Remember, from the previous lesson, the endosymbiotic theory explains how prokaryotic cells evolved to become eukaryotic. But how did the unicellular eukaryotic cells become multicellular? There are three major theories: the symbiotic theory, the syncytial theory and the colonial theory.



ests that cooperation, or symbiosis, of different species of unicellular ıtion of multicellularity. According to this theory, each species had relationship, and that the individual cells could no longer survive on their own because they had become very dependent on each other's role in the symbiosis. Over time this symbiotic relationship gave rise to a new species, a multicellular one.

The Syncytial Theory

The syncytial theory, also known as the theory of cellularization, was proposed by Hadzi and Hanson in 1963. They proposed that the first eukaryote evolved from a primitive multinucleated protist. This protist, a ciliate type, underwent nuclear division without the usual cytoplasm division. Thus, the resulting cell had several nuclei. Over time, the organism evolved and developed cell membranes around each nucleus thus, becoming multicellular (see Figure 2).

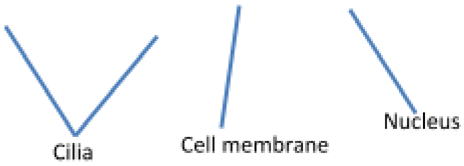


Figure 2. An illustration of the syncytial theory. A multinucleate ciliate (left) and a multicellular organism forming from a multinucleated ciliate with the formation of cell membranes around the nuclei.

The Colonial Theory

The colonial theory, proposed by Haeckel in 1874, suggests that multicellularity evolved from the symbiosis of many unicellular organisms. However, unlike that in the symbiotic theory which was by different species, the symbiosis was formed by the same species (see Figure 3). The colonial theory is the most accepted since it has been observed in many protists, particularly among the species of the volvocine algae, an example is *Volvox*.

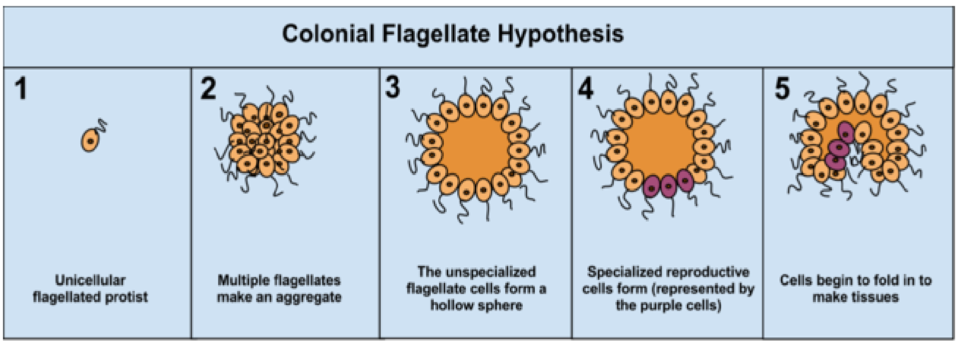


Figure 3. The colonial theory, from *The colonial flagellate hypothesis* by Katelynp1 (2012), https://en.wikipedia.org/wiki/Multicellular_organism#/media/File:ColonialFlagellateHypothesis.png. License: CC BY-SA 3.0

Volvox is a colonial organism made up of more than 1,000 cells grouped together and forming a hollow sphere (see Figure 4 and 5). Cells within the colony have specific functions, for example, some have eyespots which enable the colony to swim to a light source.

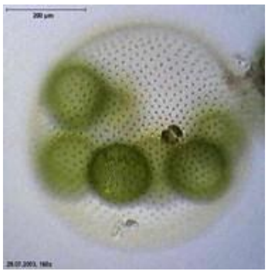


Figure 4. A colony of *Volvox*, from *Organization of cells* by CK-12 Foundation, https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_Introductory_Biology_(CK-12)/02%3A_Cell_Biology/2.12%3A_Organization_of_Cells. License: CC BY-NC-SA 3.0

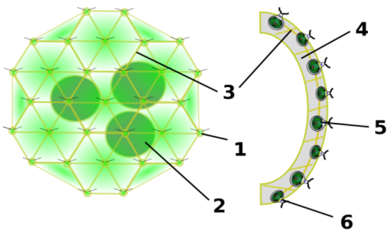


Figure 5. Volvox colony: 1) flagellated cell, 2) daughter colony, 3) cytoplasmic bridges, 4) intercellular gel, 5) reproductive cell, 6) somatic cell, from *Volvox* by Sundance Raphael (2007), https://en.wikipedia.org/wiki/Volvox#/media/File:Volvox.svg. License: CC BY-NC-SA 3.0

There are other species of the volvocine algae that exhibit colony formation. They vary in size and complexity with cell numbers ranging from four (B) to thousands (H) (see Figure 6). The cells within the colony may be undifferentiated (all cells reproduce asexually and sexually) and resemble *Chlamydomonas* (A). For those colonies with differentiated cells, the somatic cells are smaller and the reproductive cells are larger and not flagellated.

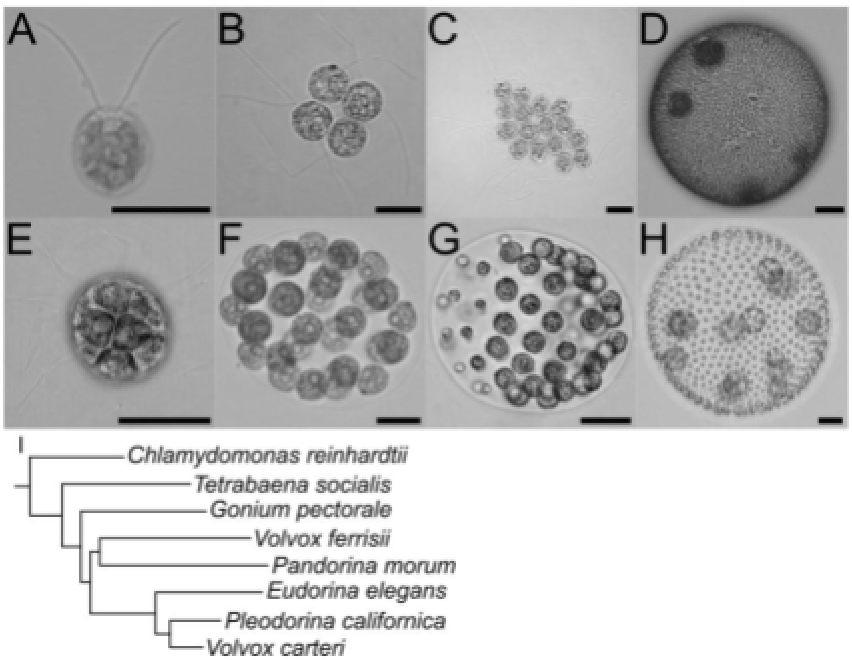


Figure 6. Micrographs of select volvocine genera (same order as in I.);
A. *Chlamydomonas* (scale bar, 10 µm), B. *Tetrabaena* (10 µm), C. *Gonium* (10 µm), D. *Volvox ferrisii* (50 µm), E. *Pandorina* (25 µm), F. *Eudorina* (25 µm),

G. *Pleodorina* (50 μm), H. *Volvox carteri* (50 μm). I. Phylogenetic tree of select volvocine species, from Evolution of Individuality: A Case Study in the Volvocine Green Algae by Hanschen, Davison, Grochau-Wright & Michod (2017), https://quod.lib.umich.edu/cgi/t/text/text-idx?cc=ptb;c=ptb;c=ptpbio;idno=6959004.0009.003;g=ptpbiog;rgn=main;view=text;xc=1. License: CC BY-NC-ND 4.0

Why is there a need for multicellularity?

The volvocine species are said to resemble the ancestors during the evolution from being unicellular to multicellular. **But why was there a need to evolve?**

One main reason is the limit to cell size. All cells need nutrients; they get these nutrients from their surroundings and they also release waste products into the environment. Thus, cell growth is dependent on the rate of diffusion of materials into and out of the cells. Unicellular organisms have high surface area to volume ratio; and the higher the ratio, the more effective the diffusion of materials in the cell. However, as the cell grows larger, the cell's surface area to volume ratio becomes smaller.

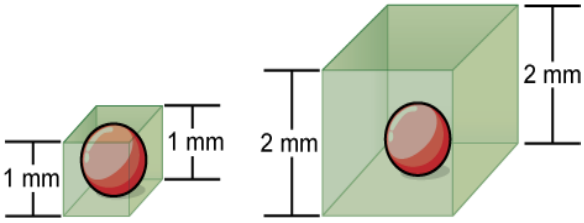


Figure 7. Surface Area to Volume Ratios**:** Notice that as a cell increases in size, its surface area-to-volume ratio decreases. When there is insufficient surface area to support a cell's increasing volume, a cell will either divide or die. The cell on the left has a volume of 1 mm3 and a surface area of 6 mm2, with a surface area-to-volume ratio of 6 to 1, whereas the cell on the right has a volume of 8 mm3 and a surface area of 24 mm2, with a surface area-to-volume ratio of 3 to 1, from *Cell size* by Boundless (2020), https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_General_Biology_(Boundless)/4%3A_Cell_Structure/4.1%3A_Studying_Cells/4.1D%3A_Cell_Size. License: CC BY-NC-SA 3.0

One way to get around this problem on limits to cell size is for the cell to increase surface area and decrease effective volume. Some species achieve this by being rod-shaped, as exemplified by the rod-shaped bacteria or bacilli. Another way is to increase the rate of diffusion by moving towards areas with high concentrations of nutrients and improving nutrient transport within the cell and this is displayed by motile protists and amoeba. However, for organisms to really become more adapted to their environment and colonise a niche, they have to be better than just staying unicellular. This they achieved by having division of labor within the cell (becoming eukaryotic) and division of labor between cells (forming a colony). Over time these colony-forming species evolved to become multicellular organisms.

NAVIGATE

Answer the following items. (This is a non-graded assessment.)

1. Cell A has a surface area of 20 μm^2 and a volume of 5 μm^3. Cell B has a surface area of 35 μm^2 and a volume of 10 μm^3. Based on the information given, which cell has the fastest rate of diffusion?

2. The small size of cells best correlates with ___________.

A) the fact that they are self-reproducing.
B) their prokaryotic versus eukaryotic nature.
C) an adequate surface area for exchange of materials.
D) the fact that they come in multiple sizes.
E) All of these are correct.

3. Which theory for the evolution of multicellularity would be exemplified by protists of different species forming a colony and cooperating when conditions are harsh?

Multicellularity evolved in organisms to solve the problem in the limit to cell size and to enable them to colonise an environment. There are three major theories that explain the evolution of organisms to multicellularity: the symbiotic theory, the syncytial theory, and the colonial theory. Among these theories, the colonial theory is most accepted by scientists as this can be widely observed among the volvocine species.

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