A (Brief) Introduction to Biology:

In this course we will attempt to build your understanding of biological systems. These systems include familiar things like cells, humans, fishes, butterflies, bacteria, plants, and the rest of life on this planet. Biological systems are **physicochemical systems** with a history shaped by evolutionary processes over billions of years. That is, all biological systems are governed by the laws of physics and chemistry. This means that biological systems and their emergent properties, even properties as amazing as dreaming and laughing, depend upon a common set of natural laws and so can be studied scientifically.

We can think of cells as the atoms of life. Atoms are the smallest units of matter in the universe and cells are the smallest units of life on this planet. All living "things" are composed of one or more living cells. Living "things" or what biologists call organisms and if you were to discover a new organism on this planet, it would be made of one or more cells.

The Cell Theory holds that all cells are derived from pre-existing cells. It does tell us where the original cells came from. So, the simplest organisms consist of a single cell but there are also multicellular organisms made of many cells. In general, organisms are **non-equilibrium**, **homeostatic**, and **adaptive** self-replicating systems.

Based on the fossil record and comparison of cellular and molecular similarities of living organisms, it appears that all organisms now living on earth are derived from a common ancestor, known as the "last universal common ancestor" (LUCA), which lived between 3.5 to 3.8 billion years ago.

Since then, cells (and organisms) have been formed from pre-existing cells (and organisms), forming a single, unbroken tree of life. This is just one of many strangescientific conclusions.

The diversity of organisms that exist and have existed on this planet were generated by processes of evolution, which include: gene and genome duplication, mutation, selection, and random (non-selective) processes (e.g., genetic drift.

Different types of organisms, known as species, are defined as different by their "reproductive isolation" from one another. For example a human and an oak tree are different species because they can not produce offspring that can go on to produce their own offspring (It is advisable to avoid the temptation to prove this as false!).

It is estimated that there are > 1,500,000 (1.5 x 10^6) species of living organisms, of which about ~750,000 are insects, ~250,000 are plants, and ~41,000 are vertebrates (you are a vertebrate and ">" means greater than and "~" means "approximately").

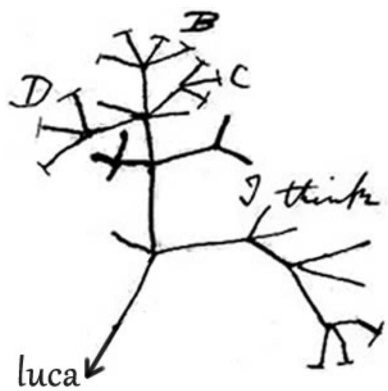

Figure 1: *Figure: Charles Darwin's tree of life that represents the branching process of evolution. Living organisms are leaves at the ends of branches. Every organism, including yourself, can trace their ancestry to single point (LUCA) at the base of the tree.*This point represents the origin of life

The number of distinct microbial (e.g., bacteria, protists and other single-celled organisms) species remains difficult to determine accurately, in part because of the ubiquity of what is known as "horizontal gene transfer" and the lack of sexual reproduction in such organisms. As you can see, our current definition of a species (i.e., reproductive isolation) is difficult to apply to all life-forms. Defining what species is can be a difficult task for biologists (but we like challenges!).

While there are currently millions of species alive today, over the course of Earth's history there have been even more. Most types of organisms that have existed no longer do, they are extinct. To be extinct means that a lineage (i.e., branch on the tree of life) has no living descendants.

Today there are organisms that range in size from less than 0.000001 (10^{-6}) meters (1 µm) to more than 30 meters long, a range of over 107 fold.

Figure: The size of life. Click the image to learn more about the scale of life

As you already know, organisms range from those consisting of a single-cell, known generically as microbes, to multicellular plants and animals, which can contain over 10^{14} (trillions) distinct cells.

A particular type of organism can live independently or in communities, and different types of organisms live together in ecosystems. For example, microbes often live together in biofilms (e.g., plaque buildup on teeth). Within a biofilm, organisms can cooperate or compete (or both) with one another in complex and

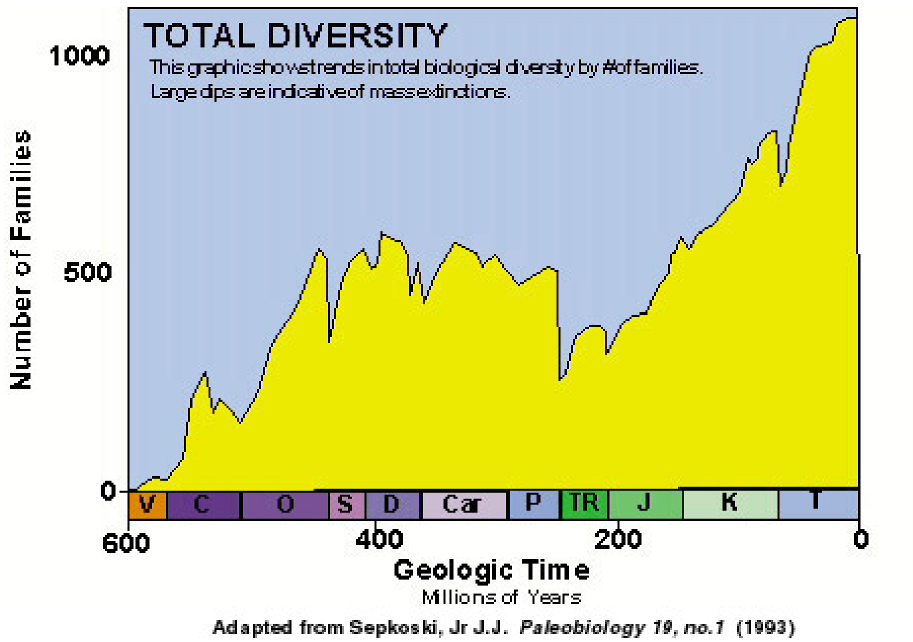

Figure 2: The history of life is punctuated by multiple mass extinctions.

evolving ways. Right now, there are many microbes living within your gut, and together with you, they form an "enteric" ecosystem". Look out the window to see both microscopic and macroscopic ecosystems in action.

The simplest form of multicellular organisms are colonies of related cells, held together in loose aggregates. In these simple colonial organisms, all cells can reproduce or divide to make new organisms. A major innovation in the history of life was the appearance of "true" multicellular organisms.

Multicellular organisms have different types of cells that carry out different functions and only a small subset of cells, known as **germ cells** (e.g. found in the testes and ovaries of humans) produce the next generation of organisms. Other cells, known as **somatic cells**, form the body of the organism, and perform specific roles like: secretion of enzymes to digest food, production of energy (ATP; see below), movement, cognitive abilities, and (taken together) all other functions and actions of the organism. What makes you you (i.e., the actions and functions of your body) are the actions and function of your cells.

The cells of multicellular organisms "cooperate" (instead of competing) to ensure that they all survive. In a multicellular organism, control of cellular behavior is critical and complex. For example, when somatic cells begin to divide in an uncontrolled (anti-social) manner, the result is cancer. To guard against anti-social and competitive behavior, multicellular organisms (and social groups) use various strategies.

The concept of inclusive fitness has allowed evolution to produce both multicellular and social organisms, like humans, in which a range of interactions are critical for reproductive success. These same evolutionary mechanisms have produced Eusocial organisms, where individuals act as a part of super-organism; bee hives and naked mole rat colonies behave in this way. In eusocial organisms, only a limited subset of organisms reproduce to form the next generation, just like the germ line cells of a multicellular organism

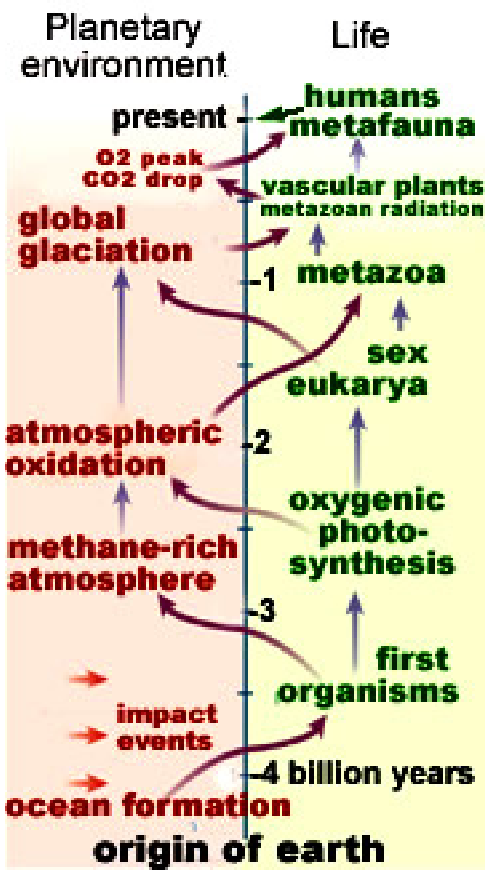

Figure 3: Life and its interaction(s) with the environment over time

Organisms interact with one another and their physical environment to form ecosystems. These interactions take many forms, including predator-prey, host-pathogen, and various forms of interdependence: parasitism, symbiosis and mutualism.

In an ecosystem, organisms have to deal with the impacts of other organisms on their physical environment.

The most dramatic life-based environmental impact to date has been the generation of molecular oxygen (O_2) as a waste product of one form of photosynthesis. O_2 is highly reactive. Its accumulation transformed the conditions under which most organisms lived, and they either had to adapt or find an environment in which O_2 was not present.

While a catastrophe for some, the appearance of O_2 was an opportunity for others; it made possible the emergence of large, active multicellular organisms, such as ourselves.

Questions to answer:

1. Why is the "Cell Theory" not a fact?
2. Describe what it means to be a non-equilibrium system;

- a homeostatic system;
- an adaptive system;
- an evolving system.

3. How do you measure the fitness of an organism?

4. Provide an example of how we know that O_2 is highly reactive.

5. Reproductive isolation is one way to define a species, what are some other ways that we might define a species?

6. Is an ecosystem an equilibrium or a non-equilibrium system?

Questions to Ponder:

1. What are the differences between a multicellular organism and an ecosystem?
2. Can you think of advantages and disadvantages of being unicellular vs. multicellular?
3. Do you think there are functions or actions of the human body that are not based upon actions or functions of cells?

Common features of cells, the basic unit of life:

All cells share a large number of common features, inherited from their ancestors in an unbroken tree of life that goes back ~4 billion years. In analogy with computers, all cells use a version of the same basic operating system.

They store genetic information in molecules of deoxyribonucleic acid (DNA). To use this information it must be first transferred into a molecule of ribonucleic acid (RNA). The DNA-dependent synthesis of RNA is known as transcription that is, DNA is copied (transcribed) to RNA. RNA molecules have a number of roles in cells, one of which is to direct the synthesis of proteins - this process of RNA-directed protein synthesis is known as translation. Translation is performed by a catalyst composed of RNAs and proteins, the ribosome. With each new cell formed, DNA is replicated and the "daughter"cell receives a copy - a copy is also retained by the mother cell.

DNA is not completely stable and replication is not error free; changes in the DNA (mutations) occur, although most are repaired. With minor (explicable) variations, all organisms use the same universal code that links DNA sequences to protein sequences. The genetic code is a universal code for all life.

Replication, transcription, and translation are chemical reactions that require energy to occur. This energy is captured from the external world; from outside the cell. Cells store much of this energy for immediate use in molecules of adenosine triphosphate (ATP). The hydrolysis or chemical breakdown of ATP using water to form ADP (adenosine diphosphate) + phosphate is a thermodynamically favorable reaction (occurs readily in the cell), and can be coupled to unfavorable reactions in order to drive those unfavorable reactions (occurs less readily inside cells).

Many of the chemical reactions used to capture energy, to build and disassemble macromolecules (e.g. proteins and nucleic acids), are common to all cells. Cells and all life share a common central metabolism.

Cells have a boundary layer, a plasma membrane, that separates their insides (called cytoplasm) from the external world. This membrane is composed of a lipid bilayer and embedded and associated proteins.

Features of all cells

- Information is stored in DNA using a universal code (this enables us to use the fossil record and DNA sequence comparisons to map the relationships between living organisms.)
- DNA acts as the template for RNA synthesis (transcription).
- Many RNAs encode polypeptides (proteins); the synthesis of polypeptides (translation) is catalyzed by ribosomes.
- Cells are surrounded by lipid-protein membranes.
- Imported energy is used to maintain cellular structure and to build new cells.
- Cells share many common chemical reactions (metabolism).
- Cells store chemical energy in molecules of adenosine triphosphate (ATP) as well as in ion gradients across membranes.
- Cells couple thermodynamically favorable reactions to drive thermodynamically unfavorable reactions (including replication, transcription,

translation).

The Theory of Evolution:

Because DNA is not completely stable, and because errors can occur during its replication, changes in DNA (mutations) occur and are passed on to daughter cells.

Mutations can have a range of effects on the organism that inherits them, from little or none to death. Over time, different organisms will have different genotypes (DNA) that lead to different phenotypes (different behaviors, physical characteristics, etc).

Because of their phenotypic differences, some organisms reproduce more successfully than others. They are better at surviving long enough to reproduce and passon their DNA to the next generations. Which organisms reproduce most successfully will be determined in part by interactions with their environment (which includes other organisms).

Figure 4: *Figure:A pond ecosystem*

Over many generations the differential reproductive success of individuals will lead to changes in the frequency of specific genotypes within a population. This in turn will lead to changes in phenotypes, the population will evolve.

Over time, evolution responds to changes in a population's environment, as well as changes within the population which influence reproductive success.

A population that fails to adapt rapidly enough to changes in its environment may disappear, it will become extinct.

Figure 5: *Figure: Dinosaurs are extinct reptiles.*

Populations can also divide and adapt to different environments, a process that overtime leads to reproductive isolation between populations, this process produces new types of organisms.

Figure 6: *Figure: Divergence within a population of beetles producing two species*

Questions to answer:

1. What would happen to the Cell Theory (and modern Biology), if an organism were discovered that did not share the features of life described above?

2. How does the Cell Theory explain the common features of cells and organisms?

3. If the environment were constant, would extinction or evolution occur?

Questions to ponder:

Use Wikipedia or the Penguin Dictionary of Biology or your textbook to look up concepts