Unit 1: Introduction to the Human Body and its Scientific Study

See topic and resource outline for readings, activities

I. Introduction: This semester we focus on human biology, with special attention to health and related issues. The essential science for the semester, then, is human anatomy and physiology. In this unit, we'll introduce the human body by examining essential features of its structure and function. Our major topics of discussion will be

   A. how we know what we know: the process of science applied to studying humans
   B. the structural organization of the human (animal) body
   C. overview of cell structure and function
   D. overview of the structure and function of the major tissues
   E. overview of organs and organ systems
   F. overview of materials exchange and homeostasis

II. How we know what we know: Reviewing the scientific process in the context of health and diet

   A. We are increasingly bombarded with information about our health. As consumers, we need to know how to decide which information is worth paying attention to and which is junk or pseudoscience.
   B. Reviewing the basic process of science:
      1. Example: using the process of science to discover the origin of a new disease - SARS
      2. Science is a way of learning about and explaining the **empirical** world
         a. the empirical world is verifiable through observation or experimentation
            (1) this means it is the world that is perceived by our senses (or instruments that extend the range of our senses)
         b. **verifiable** means that what we observe must be observable by others in the same way
            (1) This is important – observations that can't be verified fall outside the realm of science!

c. Although scientific knowledge can influence other realms of thought, science can't tell us what's "true" or "false" about anything except the empirical world – everything else falls outside the realm of science (e.g., ethics, religion, morality, public policy, aesthetics, etc.)

d. So, in the case of SARS – scientific study/findings

(1) **could be used** to

(a) identify the cause and origin of the disease

(b) develop treatments

(c) develop strategies to prevent the spread of the disease (e.g., quarantine affected individuals, restrict travel to/from affected areas)

(d) develop diagnostic tests to identify the disease early in an outbreak

(2) **could not**

(a) assign "blame" to individuals, governments for the course of the disease

(b) determine specific public policies dealing with affected individuals (e.g., how quarantines would be established and enforced; how travel restrictions would be enforced; etc.)

3. Scientific understanding grows when we take observations about the empirical world and interpret them according to specific rules:

a. Science uses only **mechanistic explanations** (nothing supernatural). If it has a supernatural explanation, it's not science. In the case of diseases, e.g., we no longer consider them to be caused by demons, or to be divine punishments for human misbehavior/sins.

b. When two or more explanations fit the observations, the simplest is most likely to be correct. This is the principle of **parsimony**, or Occam's razor (illustrated in the movie *Contact*).

c. Scientific explanations must be **consistent with all the available empirical evidence**. Explanations can be modified – facts cannot! Because scientists are always making new observations, our scientific explanations are always being tested, revised, and improved (or increasingly strongly supported if they continue to fit with new observations)

(1) E.g., in the case of SARS, several different microbes were identified as possible causes – but most could be ruled out because they weren't present in all affected individuals.

d. Scientific explanations obey the principle of **uniformitarianism**, which holds that processes operate now the same way they have in the past, and will continue to do so in the future. Explanations that require processes to work in fundamentally different ways at different times aren't scientific. Uniformitarianism is important because it allows us to build on previous knowledge when we're trying to explain something new:

(1) E.g., the symptoms of SARS and the way it spread were consistent with what we already knew about how other respiratory viruses worked. That let scientists focus very quickly on the most likely causes, rather than testing every possible cause.

e. Scientific explanations are **testable and falsifiable** – this is a key difference between science and religion, e.g., or science and pseudoscience.

(1) E.g., the explanation that a disease is caused by evil spirits or divine punishment isn't testable or falsifiable – there's no way to prove it's wrong. Therefore, it's not a scientific explanation.

(2) Even when it follows all the rules above, scientific explanations aren't accepted just because they're plausible – they always have

to be tested and either supported or rejected.

(3) To be testable, scientific explanations must make **predictions** that can be proven wrong through experiments or observations. If an explanation can't provide falsifiable predictions, it isn't scientific. E.g., in the case of SARS (and other diseases):

(a) The "explanation" we're looking for – the hypothesis we're testing – is "this microbe causes the disease".

(b) Two important tests are based on key predictions:

i) "If this virus is the cause, then it will be present in all affected patients." If a virus wasn't present in all affected patients, it was rejected as the cause.

ii) "If this virus is the cause, then if we inject a susceptible host with the virus, the host will contract the disease." If a host didn't contract the disease, the virus was rejected as the cause.

4. Some other important things to remember about science:

a. Scientific explanations can be "disproven 100%", but not "proven 100%". What we try to do is support explanations through enough tests that they are "proven beyond reasonable doubt."

b. Scientific explanations are always subject to revision and change as new observations and evidence become Even explanations we're very sure of are always subject to change if new evidence becomes available.

C. Scientific knowledge (about anything!) accumulates as many hypotheses are repeatedly tested by many different scientists using many different methods.

1. Remember that hypotheses are never "proved" – they are either supported or rejected.

2. In practice, when many different scientists are studying complex

phenomena (such as those involved in human health) using many different methods, some will support and some reject the same hypothesis.

3. Over time, as more studies are done and more evidence accumulates, we judge the validity of a hypothesis by the “weight of evidence” - like a balance. We can get a continuum of levels of support for a hypothesis:
   a. When many studies (especially done by different scientists using different approaches) support a hypothesis and only a few reject it, we accept the hypothesis as well established or well supported – e.g., the link between moderate alcohol intake and reduced risk of heart disease is well established (more on this later)
   b. The weight of evidence may not be this strong, either because few studies have been done (why might that be?) or because one or two important studies cast some doubt. In this case, we may be able to conclude that the hypothesis is probably correct.
   c. Sometimes we only have a very few, small studies suggesting that an interesting hypothesis may be correct – in this case, we’d say that the hypothesis is possibly correct, but needs more study before it is even granted the level of “probably correct.” E.g., a recent analysis of 19 different studies concluded that taking high doses of vitamin E (more than 400 mg daily) increases the risk of death in older people. But, although the sample size was large, the population studied (older people, some with existing health problems) isn’t representative of the general population, so this needs more study.
   d. At the other extreme, we may have a hypothesis that looked possible, but on further testing turned out to be unsupported by the evidence. In this case, the hypothesis is rejected. E.g., Although it’s well established that vitamin C supplements can lessen the duration of a cold, there is virtually no support for its ability to prevent colds.

D. We determine the weight of evidence by the number, kinds, and quality of studies that have been used to test the hypothesis.

1. Remember basic vocabulary from last semester: we're talking about explanatory = "hypothesis-testing" science.
2. Two broad categories of studies can be used to test hypotheses:
   a. **Experimental** studies test hypotheses by manipulating subjects/conditions and comparing outcomes to control (unmanipulated) subjects/conditions.
      (1) Experimental studies are powerful because they allow investigators to study single factor/variable at a time
      (2) Experimental studies in humans can be problematic for several reasons:
         (a) ethics: we can't ask humans to make changes that we know or suspect will harm them!
         (b) expense: these studies are very expensive, and funding is limited
         (c) adherence: when the experimental intervention is complex (like a change in several aspects of diet), subjects may have a hard time maintaining compliance
         (d) for practical reasons, can usually only involve very small sample sizes
   b. **Observational** studies compare people whose health/lifestyle habits differ, but without any direct intervention.
      (1) Observational studies are useful because they potentially allow for large sample sizes (hence more reliable conclusions).
      (2) Observational studies are problematic for several reasons:
         (a) reliability: many observational studies require that people report past behavior, and memories aren't always reliable

(b) time: the best observational studies require that we collect data over many years (10 minimum for the best studies)

(c) expense: studies involving large numbers of people over long periods of time can be even more expensive than experimental studies.

E. What types of experimental studies do we use to test hypotheses about human health?

1. **Laboratory and non-human animal studies**

a. These studies use a variety of “subjects”, ranging from cultured human cells and tissues to different kinds of laboratory animals.

b. Advantages:

(1) relatively inexpensive and can be very carefully controlled

(2) good way (sometimes the only way) to study details of cellular mechanisms associated with the phenomenon in question

(3) disadvantages = results aren’t always generalizable to humans: cells aren’t whole bodies; mice aren’t people

2. **Randomized double-blind placebo trials**: the “gold standard” of experimental procedures

a. The basic protocol in these trials is:

(1) Subjects ideally represent a good cross-section of the population (e.g., men and women, range of ages, etc.)

(2) Subjects are randomly assigned to either experimental or control treatments - randomization avoids problem of compounding variables (e.g., if all experimental subjects men, all controls women – are differences due to sex or treatment?)

(3) The control receives a “placebo” (the simplest placebo is, e.g., a sugar pill in place of a vitamin; it can be more complicated than that) – this controls for the effects of the experimental manipulation (e.g., swallowing a pill, psychological affect of

"believing" you're being treated)

(4) Neither the experimenters nor the subjects know who got the placebo and who got the real treatment (this is what "double-blind" means). This is important for controlling:

(a) subject's responses (if a subject knows s/he got a placebo, s/he might not exhibit a placebo effect – and that might make a difference appear that isn't real)

(b) experimenter's bias in recording the subject's responses (if the experimenter knows who got the placebo, it's very possible that s/he might unconsciously bias the results recorded)

b. These are the "gold standard" of experiments because they are so well controlled. But:

(1) they're expensive

(2) they usually have limited sample sizes and short durations

(3) they're hard to design for complicated interventions, such as complex dietary changes (anything for which a placebo is difficult to design)

F. What kinds of observational studies do we use?

1. **Cross-cultural studies**

a. The basic protocol is to compare lifestyle differences (e.g., diet, exercise, alcohol consumption, etc.), and health outcomes among different countries, ethnic groups, etc.

b. Advantage is that we historically have many different cultures with many different types of lifestyles, so have lots to compare

c. Disadvantages are that

(1) Different groups can differ enough biologically that outcomes don't "transfer" – a healthy diet for Inuits may not be healthy for Caucasians, e.g.

(2) Can be difficult to identify individual "causes" – lifestyles usually differ in many ways, so figuring out which one difference is associated with a particular health outcome is tricky at best.

(3) Cultures are changing rapidly, so current information on diet/lifestyle may not reflect historical patterns

2. **Case-control studies**
   a. The basic protocol for these studies is:
      (1) identify a group of people with the condition/outcome of interest (e.g., high blood pressure, osteoporosis, etc.) – these are the cases
      (2) match them with a similar group of people without the condition – e.g., same age, sex, ethnicity, etc. – these are the controls
      (3) Look for specific differences in past behavior/treatment/etc. between the groups that might be associated with the difference in the condition (e.g., differences in diet, exercise, vitamin supplements, etc.)
   b. Advantages = relatively quick, inexpensive – data can often be obtained simply from health records and simple interviews
   c. Disadvantages = results can be unreliable if differences are complicated and/or need to be remembered (e.g., "took 500 mg of vitamin C daily for 5 years" rather than "got a flu shot in the last 6 months")
3. **Cohort studies**: these are the "gold standard" of observational studies of human health (also called "longitudinal" or "prospective" studies)
   a. Protocol
      (1) Follow very large groups of people over very long periods of time
      (2) Regularly gather information about many different variables
      (3) After specific periods of time, compare characteristics of different

sub-groups to test hypotheses (e.g., people who develop a specific form of cancer vs. those that don't – what lifestyle differences are correlated with the difference in outcome?)

b. Advantages:

(1) Don't rely on information from the past, so data reliable (which makes outcomes more reliable)

(2) With large numbers of people, sample sizes are large and often represent a good cross-section of the population

c. Disadvantages: time and money!

d. Two of the largest and most important cohort studies for diet, exercise and health are from Harvard:

(1) The **Nurses' Health Study** began in 1976 with over 100,000 female nurses across the country; it was originally designed to help study the effects of oral contraceptives and was expanded to study diet and many other lifestyle variables. Participants complete questionnaires every 2-4 years.

(2) The **Health Professional's Follow-up Study** began in 1986 with over 50,000 male health professionals; it was designed to study the effects of diet and other lifestyle variables on men's health

G. How do we get the information we need from all these scientific studies?

1. Review types of information sources:

a. **Peer-reviewed technical publications** are the "gold standard"

(1) Scientists use these to communicate with one another.

(2) In the peer-review process, a scientist's work is evaluated by other experts in that field before the paper is published. Papers will be critiqued and revised before publication; bad science is much less likely to be published because of this.

(3) Scientists are required to report all of their methods and results so

others can replicate and/or evaluate their work independently – data may be reanalyzed, conclusions debated, etc. This gives "transparency" to the process – we know exactly what the facts are and how conclusions were drawn from them.

(4) The problem with peer-reviewed technical publications is that few of us are sufficiently knowledgeable (or have the time!) to read and critically evaluate all the scientific studies that are potentially relevant to our lives – so we rely on the next step . . .

b. When new discoveries are reported by scientists, that information usually gets to the public via the print and television **news media**.

(1) Major media outlets (and wire services) have journalists who specialize in science and technology – they keep their eyes out for newsworthy discoveries.

(2) The "good news/bad news" about science reporting:

(a) Reporters are usually trained to do a pretty good job of "translating" complex science for non-scientists to understand.

(b) To the extent that they work for a company that has high standards, what they report will be relatively fair, balanced, and accurate.

(c) Even well-trained reporters may miss important nuances .

(d) Space and time limitations may prevent important aspects of studies from being reported adequately.

(e) To the extent that they work for a company with a particular editorial bias, what they report may be slanted.

c. A variety of **non-technical science publications** are directed to non-scientists interested in science (e.g., *Scientific American*, *Omni*, *Discover*)

(1) The advantage of these sources is that they offer more in-depth analysis and coverage than traditional news media. They also generally offer specific bibliographies and references to peer-reviewed work.

(2) But they can't cover everything – you can't always get a good, current article on something you're especially interested in.

d. **Non-profit foundations/organizations** provide a wide range of information on health-related topics – e.g.,

(1) Non-profit "disease" foundations and associations (American Cancer Society, e.g.) provide information on specific health issues

(2) The Mayo Foundation, associated with the Mayo Clinic, provides information on many different health-related topics

e. **Junk science/pseudoscience**: Tabloids, infomercials, ads for miraculous weight loss or cures, etc. often try to appear scientific, but aren't. How can you tell?

(1) **testimonials instead of data**: anecdotes or personal stories are used instead of reporting data from carefully designed, peer-reviewed scientific studies

(2) **no source information:** claims are presented, but no information about who conducted the studies or where they were published

(3) **financial motive:** if someone is trying to sell something for profit, that's a clue that the motive is financial rather than educational or informational

f. The **World Wide Web** – very tangled!

(1) Remember that the web is a delivery mechanism – the quality of information depends on its source, not the fact that you found it on-line.

(2) The web has lots of good, reliable science info; all of the sources

listed above can be delivered on-line as well as in print.

(3) But remember – anyone can publish anything on the web, so you have to be careful to check the sources of the information.

2. So how do we evaluate what we hear/read? We ask questions! And if the questions aren't addressed in the article itself, then we are very cautious about accepting the story at face value. Questions (like the ones you use in your writing assignments, but more detailed and specific) include:
   a. *How many studies are being reported?* One study is rarely enough to make a major change against current best practice.
   b. *Where were the studies published?* Studies published in top scientific journal usually carry more weight than, for example, internal studies done for a pharmaceutical company.
   c. *How large is the study?* The bigger the sample, the more reliable the study (as a general rule)
   d. Was the study population representative? Results from a study on retirees may not be applicable to young adults; results from one ethnic group may not be applicable to another.
   e. *What kind of study was it?* The outcome of a large cohort study is generally going to be more reliable than a small study of lab mice, e.g.
   f. *What did the study actually look at?* Did the investigators use actual diseases, or "markers" ("early warning signs") of the disease? A reduction in bone density doesn't always result in osteoporosis, e.g.
   g. *Who did the study?* Much of the science done on human health is funded by organizations with a financial stake in the outcome (pharmaceutical companies, food companies, etc.). This doesn't necessarily mean the science is bad – but it does suggest some caution.
3. Remember – when it doubt about health-related information, consult a

qualified health professional!

H. *Summary:*

1. *The science of human health is the same as any other kind of science. The science of human health deals with the empirical world; explanations must be consistent with the empirical evidence, follow the rules of parsimony and uniformitarianism, and be testable and falsifiable.*
2. *Scientific knowledge accumulates as many different scientists test hypotheses using many different methods. Hypotheses must be repeatedly tested and supported before they are accepted, and we must be able to distinguish between hypotheses that are well-supported, those that are probably correct, those that are only possibly correct, and those that have been disproven.*
3. *Scientists use a combination of experimental and observational studies to test hypotheses about human health.*
   a. *The experimental studies are typically either laboratory studies on cells, tissues, or non-human animals or randomized double-blind placebo trials. The latter are the "gold standard" of experimental studies, but are not ideal for all kinds of investigations.*
   b. *The major kinds of observational studies are case-control and cohort studies. The latter are the most reliable and have provided some of the most important information on human health.*
4. *We can get scientific information about human health from many different sources. Judging the reliability of this information can be problematic for many reasons. By asking the appropriate questions about a media report, we can often determine whether or not it's sufficiently reliable to be worth investigating with our health care practitioners.*

III. Human bodies, like those of other organisms, are organized hierarchically. Understanding many of the topics we'll study this semester requires understanding how structure/function at one level affects structure/function at higher and lower levels. For us, the levels of concern will be (from lowest to highest):

1. **Molecules**: Organisms are "built" out of a limited number of kinds of large molecules; to function properly, they rely on these plus some other small molecules and atoms
2. **Cells**: These are the "fundamental unit of life" – the smallest unit that exhibits all the properties/characteristics of life. Understanding cell structure/function is critical to understanding anatomy and physiology.
3. **Tissues** are collections of similar kinds of cells that perform a common task. Animal bodies (including human) are composed of a small number of basic tissue types, each with its own general type of function.
4. **Organs** are collections of different tissues that work together to perform specific tasks.
5. **Organ systems** are collections of organs that work together to perform larger-scale tasks; we will examine most of the organ systems in the human body over the course of the semester.
6. The **organism** is the highest level we'll study this semester. Organisms are collections of organ systems. Importantly, individual organisms are subject to natural selection, which ultimately shapes their structure and function at all levels, from molecules back up to individuals!

IV. Overview of cell structure and function: here we'll introduce the basic features of cells, including essential organelles and their general functions. We'll explore specific aspects in more detail as they relate to each unit throughout the semester.

A. The **surface area:volume (SA/V) ratio**: governs cell size (and lots of other stuff!)

1. To stay alive, cells (and whole organisms) must be able to exchange materials and information (in the form of chemical messages) with the external environment – e.g., they need to take up nutrients and other

necessary chemicals and eliminate wastes

2. The basic geometry of solid objects creates a potential problem for living things: imagine either a cell or a whole organism (it doesn't matter which)
   a. materials are exchanged across the **surfaces** of living things
   b. materials are used/generated by the **volumes** (the interiors) of living things
   c. a major challenge for living things, then, is to have enough surface to keep its volume alive – that is, to have a large enough surface area: volume ratio
   d. bottom line: surface area:volume ratio must be kept relatively large – too small and not enough materials will get in/out to keep object alive (on the other hand, too big presents other problems – more on this later)
3. The surface area:volume ratio depends on two characteristics of an object:
   a. **Shape**:
      (1) long, flat (ribbon-shaped) structures have lots of surface, little volume – highest SA/V possible
      (2) spherical objects have the lowest SA/V possible
   b. **Size**: for objects that approach cube/sphere (like many cells and organisms), decreasing size increases surface area:volume & vice-versa – increasing size decreases SA/V
4. For our purposes, understanding SA/V will help us understand:
   a. why most cells are relatively small
   b. why cells vary in size and shape
   c. why large organisms such as humans have elaborate internal organ systems
   d. why internal organ systems are built the way they are

B. The two basic types of cells: prokaryotes vs. eukaryotes

1. **Prokaryotic cells** are relatively small and simple
   a. Characterize the Bacteria and Archaea
   b. size is usually ~ 1/10 of eukaryotic cell
   c. structure is relatively simple:
      (1) cell is surrounded by a **plasma (cell) membrane** similar to eukaryote
      (2) most have a **prokaryotic cell wall**, some have a sticky **capsule**; we'll talk more about these when we talk about disease-causing bacteria
      (3) some have projection = **flagellum** that serves as a motile "tail" helping the cell to move
      (4) only one type of internal "organ" = **ribosome**
         (a) cellular machine that manufactures proteins
         (b) is smaller, simpler than eukaryotic ribosome
      (5) no separate nucleus or other membrane-bound organelles
      (6) genetic material consists of single loop of DNA, coiled into the **nucleoid region** of the cell
2. In contrast, **eukaryotic cells** (found in single- and multicellular protists, plants, animals, and fungi) are larger and more complex. Key differences with prokaryotes include:
   a. complex system of interior membranes dividing cell into compartments
   b. many internal **organelles surrounded by membranes**
   c. distinct **nucleus** = compartment housing the DNA
   d. genetic material = DNA organized into separate chunks (**chromosomes**)
   e. **ribosomes** larger, more complex
   f. **flagella** different structurally/functionally

C. Structure and function of eukaryotic cells

1. Internal membranes divide eukaryotic cells into compartments – several advantages to this
   a. Membranes provide surfaces for the chemical reactions (metabolism) that keep organisms alive
      (1) because eukaryotic cells are much larger than prokaryotic cells, their external membrane SA/V is lower
      (2) adding internal membranes increases the functional membrane surface needed for metabolism (increases functional SA/V)
   b. Cells can maintain distinct chemical environments in different compartments, allowing them to perform a wide range of chemical activities simultaneously
2. **Cytoplasm** = the fluid that fills the cell (technically, between the nucleus and the outer membrane)
   a. cytoplasm is water with of atoms and molecules dissolved in it
   b. chemical components of the cytoplasm can vary from place to place within the cell
   c. chemistry of cytoplasm often must be different from chemistry of the environment around the cell
3. Internal and external membranes share a common structure = **fluid mosaic**
   a. Fundamental structural component = two layers of special molecules called **phospholipids** (more on this later); think of this double layer as forming a “droplet” with water inside and outside. The double layer is called the **phospholipid bilayer**.
   b. Other special molecules are embedded in and/or attached to the phospholipid bilayer (forming the “mosaic”).
      (1) **cholesterol** helps maintain the fluidity of the membrane (allowing component molecules to move around properly)

(2) **proteins** do most of the chemical work of the membrane – they have many different functions (we'll look at many of them in detail throughout the semester)

(3) **carbohydrates** (sugars and their relatives) attached to the proteins and to the phospholipids also have many functions, often involved in identifying cells to one another

4. The **plasma = cell membrane** has many functions; among them are
   a. creates the structural boundary of the cell
   b. regulates movement of materials in/out
   c. site of communication between internal and external environment
5. The **nucleus** is the "command and control" center
   a. formed of a double layer of membrane (double layer of double layer!) = **nuclear membrane** to separate it from rest of cell
   b. contains the **DNA**, which regulates everything about cell structure and function
   c. DNA organized into many long molecules (23 pairs = 46 in humans); these are found in two different configurations, depending on what's going on in the cell:
      (1) "unfolded" and active while the cell is performing its usual tasks; DNA = **chromatin**
      (2) "packed" into compact bundles when the cell is getting ready to divide; each bundle = **chromosome**
   d. **pores** = openings in the nuclear membrane allow molecules and fluids to move in and out
6. The **endoplasmic reticulum** (**ER**) extends in a complex network from the outer nuclear membrane into the cytoplasm. ER is the major structure partitioning the cell into compartments. It also has other functions:
   a. **Rough ER** is studded with **ribosomes**; it has two major functions

(1) Ribosomes on rough ER manufacture proteins to be secreted from the cell; the ER modifies the protein and packages it into a small pouch = **transport vessicle** to begin the export process

(2) Rough ER synthesizes more membrane (both the phospholipids and proteins) – for itself, the plasma membrane, nuclear membrane, and other organelles

b. **Smooth ER** is continuous with the rough ER. Its main job is to anchor the proteins that carry out many different metabolic functions (it's a major metabolic membrane). Some of its metabolic functions include

(1) manufacturing a class of molecules called lipids – including steroid hormones (estrogen, testosterone, e.g.)

(2) breaking down (detoxifying) harmful chemicals

7. The **Golgi apparatus** receives, finishes, and packages proteins – mostly for export from the cell

a. apparatus consists of flattened stack of membrane disks

b. transport vessicles from the rough ER carry proteins to Golgi

c. inside, proteins are chemically modified, then packaged into new transport vessicles

d. transport vessicles can do several things:

(1) travel out to cell membrane, where contents can be

(a) incorporated into the membrane

(b) dumped outside the cell (into the bloodstream, e.g.)

(2) stay inside the cell if the proteins are to be used for digestion – these vessicles are called **lysosomes**

8. **Lysosomes** digest food and waste inside the cell

a. As we'll see in more detail later, to digest something is to break it down into its component molecular subunits

b. Cells need their own "digestive systems" for several reasons:

(1) they need to supply themselves with energy and raw materials (molecular "building blocks") to keep running properly; breaking down food molecules, worn-out cell components lets them do this
(2) it allows them to protect themselves from harmful bacteria
(3) it allows them to break down their own harmful waste products

c. Lysosomes work one of two ways:
(1) fuse with other vessicles, "dumping" digestive enzymes into them
(2) engulf something themselves

d. Either way, the important feature of lysosme function is that they always maintain a membrane barrier between the digestive proteins they carry and the rest of the cell!

9. **Mitochondria** are the "powerhouses" of the cell

a. They harvest chemical energy from food by chemically breaking down complex molecules and using the energy to synthesize **ATP**, the molecule that supplies energy for metabolism (ATP is sometimes called the "energy currency" of the cell)

b. Structure is different from other membranous organelles:
(1) mitochondria have two membranes creating a large internal surface area for complex chemical reactions
(2) mitochondria also have their own ribosomes and some of their own genes

c. Evolutionarily, mitochondria are prokaryotes that took up a mutualistic relationship with other cells over 1 billion years ago

10. The **cytoskeleton** provides structural support and movement

a. Structurally, the cytoskeleton is a complex network of protein-based fibers that runs throughout the inside of the cell.

b. Functionally, the cytoskeleton
(1) helps the cell maintain its shape

(2) anchors organelles in place

(3) helps organelles move

(4) helps the cell as a whole change shape and move

11. External support and connection among cells is important in functional tissues

    a. When they're organized into tissues, individual cells often need more support than just the cell membrane. Most secrete and are embedded in a sticky coating called the **extracellular matrix** (literally, "the network outside the cell"). It helps hold cells together and provides extra structural support.

    b. Three types of connections, called junctions, can join cells in tissues; each has different properties:

       (1) **Tight junctions** "sew" adjoining cells together along the entire membrane, creating a leak-proof barrier

       (2) **Anchoring junctions** "rivet" or "button" cells together at specific points. They connect the cells, but still allow molecules to move through the fluid between the cells

       (3) **Communicating junctions** hook cells together, but also form "tunnels" through the membranes that allow molecules to pass back and forth between the connected cells.

D. *Summary*

1. *Individual organisms are built hierarchically, starting with molecules, and moving through cells, tissues, organs, and organ systems. The structure/function of components at one level influencing structure/function at the next; ultimately, the entire organism's structure and function is shaped by natural selection.*

2. *The surface area:volume ratio governs many aspects of structure and function at several hierarchical levels. Material and information is*

exchanged across surfaces; to stay alive, a cell or organism must maintain the proper SA/V. SA/V is a function of both size and shape; long, flat objects have higher SA/V than do spherical objects; small objects have higher SA/V than do large objects.

3. *Two basic kinds of cells exist on earth. Bacteria and Archaea consist of prokaryotic cells. These are smaller and simpler than eukaryotic cells.*
4. *Eukaryotic cells are divided into compartments by a system of membranes; this allows the cell to maintain a large functional SA/V and to maintain different chemical conditions in different regions.*
5. *All membranes in a eukaryotic cell share a common general structure, a fluid mosaic of proteins and other molecules embedded in a phospholipid bilayer.*
6. *Eukaryotic cells contain many membranous and other organelles, each specialized to carry out one or a few tasks. A cytoskeleton of protein fibers provides internal support and the capacity for movement.*
7. *To form tissues, cells need additional protection and support in the form of an extracellular matrix. They are connected by three types of junctions, each with its own characteristics.*

V. Introduction to major tissue types, structure, and function

A. **Tissues** are collections of similar kinds of cells that work together to perform a specific function. Animals have four basic types of tissues; we'll introduce each one now, and look at each in more detail throughout the semester.

B. **Epithelial tissue** covers the outside and lines the inside

1. Epithelium makes up the skin of the body (outer lining) and the inner layer of the hollow organs & body cavities (e.g., intestines, kidney tubules, air sacs of lungs)
2. Epithelial tissues share a common structure:

   a. consists of sheets of tightly-packed cells

b. one side of the tissue is exposed either to the external environment (skin) or to the inside of the organ it lines (e.g., the inside of the intestine, the air spaces in the lungs)

c. the other side of the tissue is anchored to underlying tissues via an extracellular matrix called a **basement membrane** (this varies in structure/function depending on where the epithelium is)

3. Details of the structure depend on the specific function of the epithelium (we'll look at many of these in more detail later); the general functions are

a. **protection**: the skin and some internal linings protect underlying tissues from abrasion and invasion by pathogens

b. **secretion**: many internal organs are lined with epithelium that secretes special molecules – e.g., digestive enzymes into the intestine or mucous into the lungs

c. **materials exchange**: the epithelium lining the capillaries and lungs is thin and "leaky" to allow the passage of materials back and forth across the tissue.

C. **Connective tissue** binds and supports

1. Connective tissue is found throughout the body, where it has many different functions, all generally related to holding things together

2. Structurally, all connective tissue consists of two parts:

a. sparse collection of living cells scattered through a

b. non-living matrix , usually a web of protein fibers embedded in a fluid, jelly-like substance, or solid material

3. Six major types of connective tissue each have their own structure & function.

a. **Loose connective tissue** binds tissues, holds organs in place

b. **Adipose tissue** stores fat in collections of large, closely packed cells; fat stores energy, provides insulation, and protects organs

c. **Blood** is a connective tissue because it consists of living cells (red and white blood cells) in a non-living matrix – the plasma. Blood transports materials around the body & is a key element of the immune system.

d. **Fibrous connective tissue** forms tendons and ligaments – strong, flexible tissues connecting muscle to bone (tendons) or bone to bone (ligament)

e. **Cartilage** forms part of the skeletal system, providing both support (e.g., ears, nose) and protection (smooth surfaces surrounding the ends of bones).

f. **Bone** has cells embedded in a solid matrix of calcium phosphate. It's both strong and relatively flexible; it supports the body, protects important organs, and allows movement.

D. **Muscle tissue** lets us move (& a few other things)

1. Muscle is made from special protein fibers that are capable of lengthening and shortening (they're called contractile). Most muscles require a signal from the nervous system to stimulate contraction.

2. Animals have 3 types of muscles, each with its own structure and function:

   a. **Skeletal muscle** is attached to bones; this is what lets us move.

   b. **Cardiac muscle** forms the major tissue of the heart; it is unique in that it expands and contracts on its own (it can speed up and slow down with appropriate nervous input, but it doesn't need specific signals to beat at its usual rate)

   c. **Smooth muscle** is an important part of hollow organs such as arteries, stomach, intestines, uterus, etc. It requires specific signals to contract, but the signals are usually not under our conscious control.

E. **Nervous tissue** communicates with electrical signals

1. Nervous tissue is built from nerve cells (**neurons**), which are capable of receiving information (stimuli) and converting them into electrical signals –

which move very quickly.

2. Nervous tissue includes other kinds of cells that provide protection, support, and "enhancement" of the nerve cells (much more on this later!).

VI. Organs and organ systems

A. Organs are collections of different kinds of tissues that work together to perform a complex "task". Looking at the small intestine, e.g.:

1. The lining is made of epithelial tissue that secretes enzymes
2. The epithelial tissue is supported by a layer of connective tissue, which also holds in place the nerves (nervous tissue) and blood vessels (epithelial tissue surrounding blood – another connective tissue) that supply the epithelium.
3. Two layers of smooth muscle (running in opposite directions) contract to help move food through the intestine.
4. Another layer of connective tissue surround and supports the whole thing.

B. Groups of organs work together to perform large-scale body functions. We have 12 major organ systems. In brief, the names and general functions are:

1. The **digestive system**: ingests and breaks down food to supply energy and nutrients.
2. The **respiratory system** takes in oxygen (needed for cellular metabolism) and releases carbon dioxide (a toxic waste product of metabolism).
3. The **circulatory system** transports materials, including oxygen, nutrients, waste products, and chemical messages.
4. The **lymphatic** and **immune** systems supplement the circulatory system by helping recover fluid that leaks into tissue spaces and protect the body from disease.
5. The **excretory system** removes metabolic waste products, recovers water, and helps maintain appropriate salt/water balance in body tissues.
6. The **endocrine system** regulates the activity of other organs and organ

systems by generating and distributing chemical messages called hormones.

7. The **reproductive system** produces new individuals.
8. The **nervous system** works with the endocrine system to coordinate body activities by receiving and responding to signals from the external and internal environment.
9. The **muscular system** includes all the skeletal muscles of the body and is responsible for movement.
10. The **skeletal system** supports and protects the body and contributes to movement.
11. The **integumentary system** covers the body and protects it from mechanical injury, infection, desiccation, and overheating/overcooling.

VII. Exchange and homeostasis are two critical functions that explain much of animal structure and function.

A. **Materials exchange** means bringing nutrients and oxygen from the external environment to the inside of an animal's body, and moving waste products out of the body into the external environment. We will examine many of the systems involved in more detail throughout the semester.

1. Materials are exchanged across surfaces, but used and generated by volumes – so the ability of an animal to exchange materials well enough to survive depends on having a large SA/V.
   a. For many reasons, though, many animals (including humans) need to maintain external SA's that are small relative to their volumes (think of whales, e.g.).
   b. Animals get around this problem by having elaborate organ systems with very large internal surface areas.
2. The overall pattern of materials exchange is fairly simple. In most animals, the pattern is:

a. material (food, oxygen) is taken in from the external environment via a specialized organ system (digestive, respiratory)
b. material moves from that system into the blood
c. blood transports the material to the tissues that need it
d. within the tissues, oxygen and nutrients are exchanged for waste products
e. blood carries waste products to appropriate organ system (excretory, respiratory)
f. organ system releases waste to environment

3. The details are a little more complex. Important features to remember for now are that
   a. To keep the exchange process efficient, internal organ systems have very large surface areas. This is usually accomplished by having lots of folds (and folds on top of folds!)
   b. All cells are bathed in fluid (**interstitial fluid**) – exchange at the cellular level is actually blood -> interstitial fluid -> cell (and the other way around)
   c. The transport mechanisms we use to move materials into and out of cells are only efficient across very short distances (usually ~ 2 cell diameters). This means that
      (1) the circulatory system has to have an enormous number of very small vessels (capillaries) – that's the only way to keep each cell close to a blood vessel.
      (2) the capillaries themselves have to be extremely thin-walled and delicate to reduce the distance substances have to move.

B. **Homeostasis** refers to the ability of organisms to regulate their internal environments independently of the external environment; it is a fundamental characteristic of living things.

1. To be (and stay) alive depends on a large and complex set of chemical activities taking place within the internal environment of the organism. These, in turn, can only take place under a relatively limited set of physical and chemical conditions (conditions, e.g., of temperature, pH, salt concentration).
2. The external environment can pose problems for two reasons:
   a. Conditions in the external environment may never be what the internal environment requires (fresh-water fish, for example, live in water that is always more dilute than their own body tissues).
   b. Conditions in the external environment may fluctuate widely – sometimes they're what the internal environment requires, but not always
3. To stay alive, then, organisms need to be able to control the internal environment so that, no matter how much the external environment changes, the internal environment changes only a very little bit. This requires, in turn, that we have organ systems specifically adapted for monitoring the external environment and adjusting our physiological responses appropriately. We'll see many examples of this throughout the semester.

VIII. Summary (from tissues through homeostasis)

A. Like other complex animals, the human body is composed of four basic types of tissues organized into a number of organs, which are in turn organized into 12 major organ systems. At every level, structure depends on function.

B. Materials exchange is a crucial aspect of organismal function. For animals such as humans, our small external surface area requires that we have elaborate internal organ systems providing sufficient surface area for exchange. The general path of materials is from the external environment to blood, interstitial fluid, then cells & back again.

C. *Homeostasis is the ability to maintain an internal environment independent of the external environment; it is necessary because the chemical reactions that keep us alive can only take place under limited conditions that are not always met by the external environment. Maintaining homeostasis requires constant monitoring of the external environment and the ability to generate appropriate physiological responses to external (and internal) change*.