Teacher Notes for "How do food molecules reach our muscles? – Structure and Function of Organ Systems, Organs and Cells"[1]

In this activity, students learn about how food is digested and how the digested food molecules reach the muscles. Students analyze multiple examples of the relationship between structure and function in the organs and cells of the digestive system. Students also analyze several examples that illustrate how organs and organ systems work together to accomplish functions needed by the organism. Finally, students use a claim, evidence and reasoning framework to evaluate the claim that structure is related to function in cells, organs and organ systems.

Learning Goals

In accord with the Next Generation Science Standards[2]:

- This activity helps students to prepare for the Performance Expectations:
  - MS-LS1-3. "Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells."
  - HS-LS1-2. "Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms."
- Students learn the following Disciplinary Core Idea (LS1.A) "Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level."
- Students engage in recommended Scientific Practices, including:
  - "Constructing Explanations. Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena…".
  - "Engaging in an Argument from Evidence. Construct… and present… a written argument… based on data and evidence."
- This activity focuses on the Crosscutting Concept: Structure and function. "The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials."

Instructional Suggestions and Background Information

To maximize student participation and learning, I suggest that you have your students work individually or in pairs to complete groups of related questions and then have a class discussion after each group of related questions. In each discussion, you can probe student thinking and help them develop a sound understanding of the concepts and information covered before moving on to the next group of related questions.

A key is available upon request to Ingrid Waldron (iwaldron@upenn.edu). The following paragraphs provide additional instructional suggestions, links for recommended videos, and biological information – some for inclusion in your class discussions and some to provide you with relevant background that may be useful for your understanding and/or for responding to student questions.

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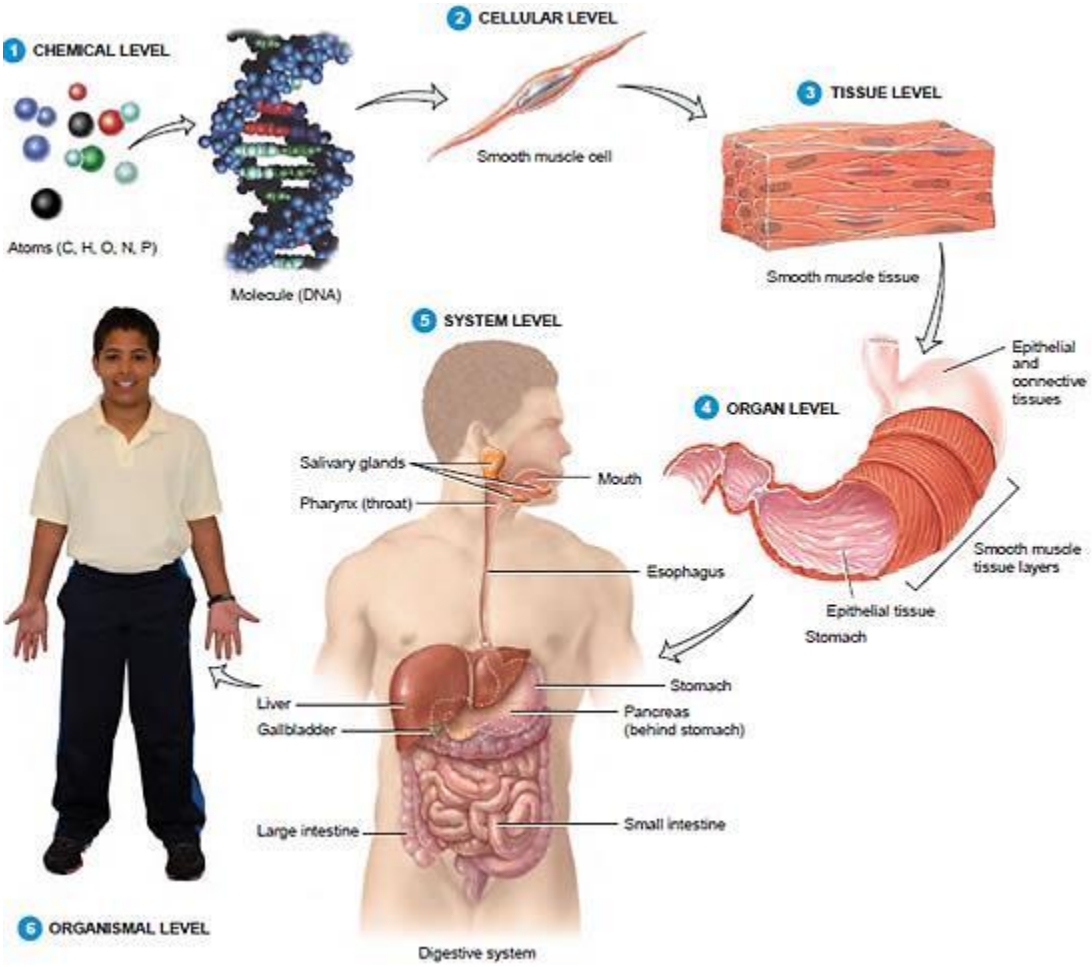
[1] By Ingrid Waldron, Department of Biology, University of Pennsylvania, 2024. These Teacher Notes and the Student Handout are available at https://serendipstudio.org/exchange/bioactivities/SFCellOrgan.

[2] Quotations are from https://www.nextgenscience.org/ and https://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf.

Questions 1-2 will help students to activate their previous knowledge and then link the new information in this activity to their previous knowledge. You may want to have a class discussion of student answers to question 1a, before your students tackle question 1b.

If you want to review levels of organization in biology with your students, I recommend the analysis and discussion activity, "Levels of Organization in Biology" (https://serendipstudio.org/exchange/bioactivities/LevelsOrganization). For a brief review, you may want to use the figure below.



(http://www.protein-structure.net/images/Body-Systems.jpg)

To introduce the digestive system, you may want to show the 5-minute video, "How Your Digestive System Works" (https://www.youtube.com/watch?v=Og5xAdC8EUI). The two diagrams of the digestive system on page 2 of the Student Handout illustrate how different diagrams of the same structure convey somewhat different information and are useful for different purposes. The first figure clearly shows the sequence of the organs in the digestive system, whereas the second figure shows the anatomical arrangement of the organs of the digestive system. These figures show several organs which are not discussed in this activity. The gallbladder stores bile, which is produced by the liver and emulsifies fats in the small intestine. The human cecum helps to absorb water and salts. Recent research suggests that the human appendix may contribute to immune function and also stores beneficial bacteria that can repopulate the rest of the gut after an illness (e.g. cholera or dysentery) has caused diarrhea that has swept most of the beneficial bacteria out of the gut (https://en.wikipedia.org/wiki/Appendix_(anatomy).

In your discussion of question 3, you should include the importance of chewing food into smaller particles which have a greater surface-area-to-volume ratio, so digestive enzymes in the small intestine will be able to reach more of the food molecules. Advantages of having food pass through the stomach before the small intestine include having stomach acid kill disease-causing microorganisms before they enter the small intestine with its large surface area and potential for infection. Also, the storage capacity of the stomach allows a person to eat large meals and gradually release small amounts of partially digested food to the small intestine. If too much food enters the small intestine too rapidly, the small intestine malfunctions and cannot digest all the food. People who have reduced stomach volume (due to surgery for cancer or weight loss) must eat small meals throughout the day.

The small intestine is roughly 3 m long. The inner surface has circular folds. The length of the small intestine, the folds in the lining of the small intestine, the villi and the microvilli all increase the surface area for absorption. This surface area is approximately 300 m^2, which is roughly the size of a tennis court! The narrow diameter of the small intestine (~2.5 cm) ensures that digested food molecules in the lumen are relatively near to the wall of the small intestine where they can be absorbed.[3] (A lumen is the cavity or space within a tubular structure.)

The cells in the epithelium that lines the inner surface of the small intestine synthesize protein enzymes that complete the digestion of food molecules. These cells also pump in sugars and amino acids, which increases absorption of these useful molecules from the lumen of the small intestine. To accomplish these functions, these cells need lots of cytoplasm with lots of mitochondria, ribosomes, rough endoplasmic reticulum and Golgi apparatus. (The latter two are needed since the digestive enzymes and pump proteins are inserted in the part of the plasma membrane that faces the lumen of the small intestine.) These metabolically active epithelial cells in the lining of the small intestine are tall and have much more cytoplasm per epithelial area than the relatively inactive flattened cells in the capillary wall. The capillary wall cells do not synthesize enzymes or pump useful molecules; instead the flattened shape provides a minimum barrier to diffusion. This is another example of how structure is related to function.

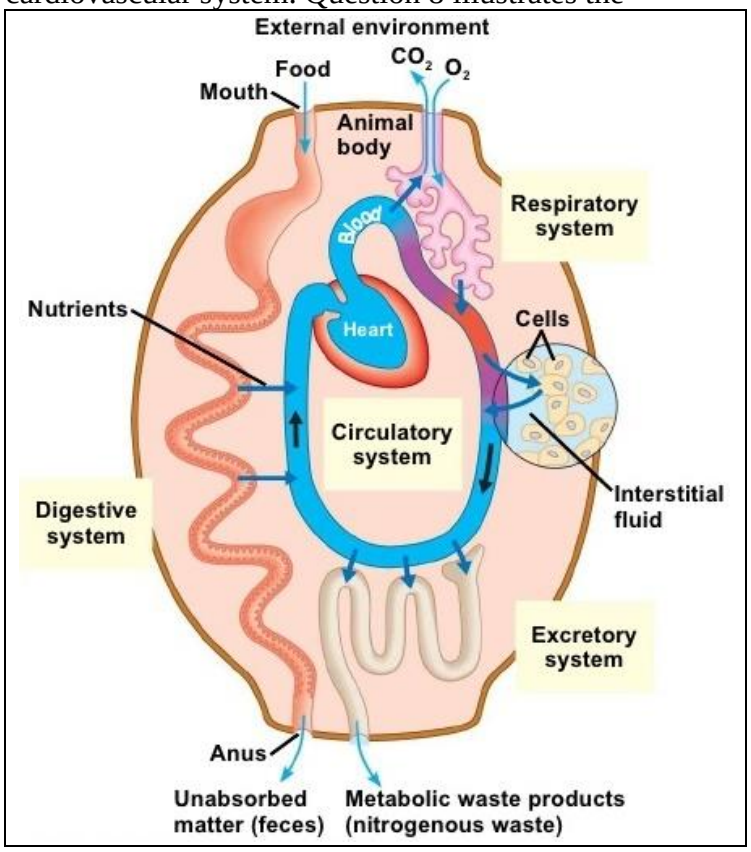
The heart pumps blood through the aorta, arteries and arterioles to the capillaries where digested food molecules and oxygen diffuse from the blood, through the capillary wall, to cells all over the body. Diffusion is reasonably rapid over very short distances, but very slow over any substantial distance. Thus, the single layer of flattened cells in the wall of capillaries maximize diffusion into and out of the blood.[4] The flattened shape of the cells also reflects the fact that the cells in capillary walls have minimal metabolic activity, so there is minimal need for cytoplasm.[5]

[3] The lacteal inside each villus is a lymph vessel; lacteals play an important role in absorption of fats. The hepatic portal vein carries blood from the small intestine to the liver, which processes some of the food molecules that have been absorbed from the lumen of the small intestine. For example, after a meal, glucose levels are high in the blood that goes from the small intestine to the liver; the liver removes some glucose from the blood and converts it to a storage form (glycogen) which will subsequently be available for use between meals. From the liver, the blood flows to the heart which pumps blood containing nutrients to capillaries near every cell in the body. Gastrointestinal hormones play an important role in coordinating the functions of the digestive system.

[4] Polar substances diffuse through the interstitial fluid between the cells of the capillary wall, whereas lipid soluble substances like oxygen and carbon dioxide diffuse across the cells. The single layer of cells around the capillary lumen is often called a simple squamous epithelium or endothelium.

[5] The same considerations explain why the alveoli in the lungs are lined by a single layer of flattened cells.

The circulatory system is also called the cardiovascular system. Question 8 illustrates the important general principle that our bodies consist of multiple body organ systems that cooperate to accomplish important functions.[6] For example, the digestive and circulatory systems cooperate to provide cells all over the body with digested food molecules that can be used for cellular respiration and as building blocks to synthesize needed molecules.



You may want to include additional examples such as the cooperation between the respiratory system and the circulatory system to provide oxygen to every cell in the body and also to remove the waste product, carbon dioxide. This highly simplified diagram illustrates how the circulatory system is crucial for allowing the specialized digestive, respiratory, and excretory systems to serve needed functions for all the cells in the body. You may also want to point out the role of the nervous system in controlling the activity of the tongue and jaw muscles and regulating other aspects of digestion.

Question 9 provides the opportunity to review the Disciplinary Core Idea, "Multicellular organisms have a hierarchical structural organization, in which anyone system is made up of numerous parts and is itself a component of the next level."

Question 10 guides students in developing a scientific argument through the "Claim, Evidence, Reasoning" or "CER" method. If your students are not familiar with this method, you may want to introduce them to the idea that, in a scientific argument, a claim is evaluated on the basis of the available evidence, with reasoning to explain how the evidence is relevant to the claim. Criteria for evaluating the validity of a scientific argument include:

- how well the claim fits with all the available evidence
- the relevance of the evidence (as explained in the reasoning)
- the quality of the evidence
- whether there is enough evidence.[7]

It should be noted that natural selection results in the observed relationships between structure and function. However, constraints on evolution often prevent optimal solutions to functional problems.

[6] A 4-minute rap video that reviews body systems is available at http://mr.powner.org/b/lessons/humans/So%20Many%20Systems%20-20Human%20Body%20Systems%20Rap.mp4.

[7] These criteria are paraphrased from Argument-Driven Inquiry in Biology (by Sampson et al., NSTA Press). This book presents a useful, more extensive format for developing students' ability to engage in scientific argument.

Additional information about the digestive system is available at:

- http://www.webmd.com/heartburn-gerd/your-digestive-system
- https://www.innerbody.com/image/digeov.html
- https://www.khanacademy.org/science/high-school-biology/hs-human-body-systems/hs-body-structure-and-homeostasis/a/tissues-organs-organ-systems.

Additional information for teaching about scientific argumentation is available at:

- http://www.scientificargumentation.com/overview-of-scientific-argumentation.html
- The Science Teacher, summer, 2013, pages 30-55, has multiple articles that suggest various ways to develop students' skills in scientific argumentation.
- http://undsci.berkeley.edu/article/0_0_0/howscienceworks_07 takes a somewhat different approach to the components of a scientific argument.

Sources for Figures in Student Handout

- Digestive system – modified from https://useruploads.socratic.org/LtW1t1ySdKXDGGeeKhpt_cub_human_lesson04_figure4.jpg
- Small intestine – modified from https://www.khanacademy.org/science/high-school-biology/hs-human-body-systems/hs-body-structure-and-homeostasis/a/tissues-organs-organ-systems and https://www.sciencelearn.org.nz/images/2259-villi-in-the-small-intestine
- Capillary – modified from https://my.clevelandclinic.org/-/scassets/images/org/health/articles/21788-continuous-capillary-illustration
- Circulatory System – modified from https://www.uc.edu/content/dam/uc/ce/docs/OLLI/Page%20Content/OLLI%20Circulatory_System.pdf

Related Activities

How do muscles get the energy they need for athletic activity?
https://serendipstudio.org/exchange/bioactivities/energyathlete
In this analysis and discussion activity, students learn how muscle cells produce ATP by aerobic cellular respiration, anaerobic fermentation, and hydrolysis of creatine phosphate. They analyze the varying contributions of these three processes to ATP production during athletic activities of varying intensity and duration. Students learn how multiple body systems work together to supply the oxygen and glucose needed for aerobic cellular respiration. Finally, students use what they have learned to analyze how athletic performance is improved by the body changes that result from regular aerobic exercise.

Cell Structure and Function – Major Concepts and Learning Activities
http://serendipstudio.org/exchange/bioactivities/cells
This overview presents key concepts that students often do not learn from standard textbook presentations and suggests learning activities to help students understand how the parts of a cell work together to accomplish the multiple functions of a dynamic living cell. Suggested activities also reinforce student understanding of the relationships between molecules, organelles and cells and the importance and limitations of diffusion. This overview provides links to web resources, analysis and discussion activities, and hands-on activities.