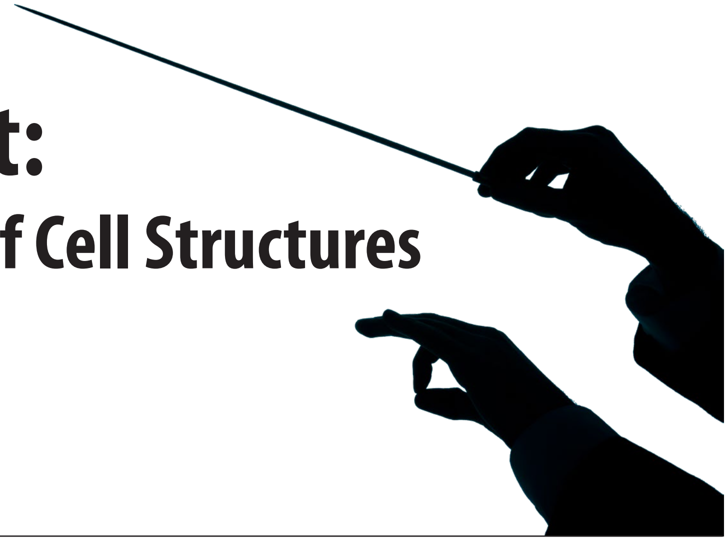
NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

# Organelles in Concert:

## Modeling the Coordination of Cell Structures



*by*

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## Sonic Hedgehog Protein Synthesis

After completing this activity, you should be able to describe the function(s) and spatial arrangement of each organelle within the cell and be able to describe the coordination among the organelles necessary for cellular function.

*Background:* Sonic Hedgehog protein (SHH) is an essential 462 amino acid protein produced in vertebrates during the early stages of embryonic development [1]. The protein is encoded by the *shh* gene, which in humans is located on chromosome 7 [2]. The SHH protein that is produced by this gene is called a "morphogen," or chemical agent that drives morphological changes in an organism. After synthesis, a cholesterol molecule is added to the C-terminal end of the amino acid sequence, and SHH is secreted by the cell into the extracellular space [3]. Once SHH is outside the cell, it forms a concentration gradient that promotes the development of several types of specialized tissue including the brain, spinal cord, and limbs and digits in vertebrates [4].

*Scenario:* Imagine that your classroom is an embryonic stem cell formed by the process of fertilization during sexual reproduction of two mice. During the first few days of development, you (the cell) receive a signal that it is time to begin the development of a spinal cord and limb tissue. Your task is to work together with your associated organelle partners to produce the SHH protein from the *shh* gene and export the final protein from the cell into the extracellular space.

### *Activity Instructions*

*Part 1: Strategize the Cellular Process*

For each of the following steps, record your responses on the provided white board (or as your instructor advises).

1. Discuss the functions of your specific organelle and what role your organelle will play in this scenario.
2. Discuss what other organelles or cell structures your group will interact with to complete the task in the scenario.
3. Construct a diagram of the sequence of events that must occur to complete the given task.
4. As a class, confirm with your instructor that the sequence of events is correct and modify your diagram with any changes. Do not go on to Step 5 until you are given permission by instructor.

*Part 2: Model the Production of SHH*

5. Assuming the walls of the classroom are the boundaries of the cell, choose the appropriate location within the "cell" for your organelle and position yourself there.
6. Using props (or yourselves) carry out the scenario from beginning to end. At each step, the members of the organelle must act out the function of the organelle and explain the details of the process to the class.

## Questions

1. Assume that during the process of creating the SHH protein an error was made. Instead of producing a 462-amino-acid-long protein, you only make a 20-amino-acid-long protein. Assume the error is detected in the golgi apparatus. Will this protein be exported into the extracellular space? If your answer is no, what will happen to this protein?

2. What if the SHH you are making needs to be accumulated in the cell so that it can be released all at once into the extracellular space at a specific time? How would you store the produced SHH? What would need to occur to release all of the SHH from storage into the extracellular space?

3. Now assume that the protein you are making is one that is not destined to be secreted into the extracellular space, but instead is meant to function within the cytoplasm. How will synthesis of this types of protein be different? Why?

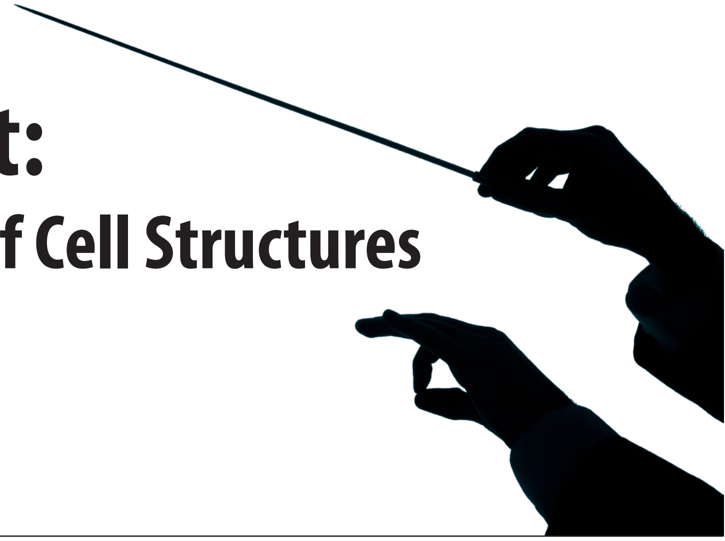
## References

[1] Katoh, Y. and M. Katoh. 2005. Comparative genomics on Sonic hedgehog orthologs. *Oncology Reports* 14(4): 1087–1090. <https://doi.org/10.3892/or.14.4.1087>

[2] Roessler, E., *et al*. 1996. Mutations in the human Sonic Hedgehog gene cause holoprosencephaly. *Nature Genetics* 14: 357–60. <https://doi.org/10.1038/ng1196-357>

[3] Li, Y., H. Zhang, Y. Litingtung, and C. Chiang. 2006. Cholesterol modification restricts the spread of Shh gradient in the limb bud. *Proceedings of the National Acadamy of Sciences of the U.S.A.* 103(17): 6548–53. <https://doi.org/10.1073/pnas.0600124103>

[4] Patten, I., and M. Placzek. 2000. The role of Sonic Hedgehog in neural tube patterning. *Cellular and Molecular Life Sciences CMLS* 57(12): 1695–708. <https://doi.org/10.1007/PL00000652>



# Organelles in Concert:
## Modeling the Coordination of Cell Structures

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## Metabolism of Carbon

After completing this activity, you should be able to describe the function(s) and spatial arrangement of each organelle within the cell and be able to describe the coordination among the organelles necessary for cellular function.

*Background:* Carbon dioxide ($CO_2$) is an inorganic gas molecule found in the Earth's atmosphere. Photosynthetic organisms can use $CO_2$ to generate organic compounds such as monomeric glucose and polymeric starch from a process called carbon fixation. This recycling of inorganic carbon (as $CO_2$) to organic carbon drives the global carbon cycle, and therefore the photosynthetic organisms, such as plants, serve as the predominant source of organic carbon for both producers and consumers alike. Organic carbon is essential for building cellular materials such as nucleic acids, protein, and fats, and the energy derived from the breakdown of organic carbon molecules drives all metabolic processes in all cells and organisms [1].

*Scenario:* Imagine that your classroom is a cell found within the leaf of an oak tree, the major photosynthetic tissue of trees. On a warm spring day, the wind is blowing, and the leaves are busy performing carbon fixation and of course cellular respiration to create energy for the cells found in the oak tree. Your task is to work together with your associated organelle partners to trace the inorganic carbon from the atmosphere through all steps of organic carbon generation and breakdown within the cell of the leaf.

### *Activity Instructions*

*Part 1: Strategize the Cellular Process*

For each of the following steps, record your responses on the provided white board (or as your instructor advises).

1. Discuss the functions of your specific organelle and what role your organelle will play in this scenario.
2. Discuss what other organelles or cell structures your group will interact with to complete the task in the scenario.
3. Construct a diagram of the sequence of events that must occur to complete the given task.
4. As a class, confirm with your instructor that the sequence of events is correct and modify your diagram with any changes. Do not go on to Step 5 until you are given permission by instructor.

*Part 2: Model the Metabolism of Carbon*

5. Assuming the walls of the classroom are the boundaries of the cell, choose the appropriate location within the "cell" for your organelle and position yourself there.
6. Using props (or yourselves) carry out the scenario from beginning to end. At each step, the members of the organelle must act out the function of the organelle and explain the details of the process to the class.

## *Questions*

1. Assume you are a house plant whose owner has gone on vacation and forgotten to provide you with a source of light for several days. Would you expect to immediately die from this absence of light? Why or why not?

2. What are your potential sources of organic carbon? Where might you store these carbon molecules?

3. Now assume you are just a little seed. You have no photosynthetic tissues yet (leaves), but you do have an abundance of fatty deposits found within your seed coat. What organelle could you use to convert the fatty nutrients into a carbon source so that you could eventually sprout some photosynthetic tissue?

## *Reference*

[1] Urry, L.A., *et al*. 2017. *Campbell Biology*, $11^{th}$ ed. Pearson Education, Inc.

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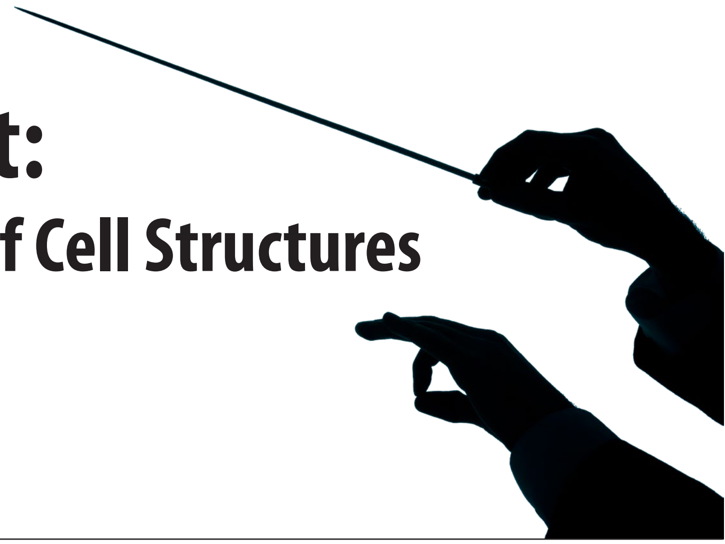

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## Phagocytosis of *Streptococcus*

After completing this activity, you should be able to describe the function(s) and spatial arrangement of each organelle within the cell and be able to describe the coordination among the organelles necessary for cellular function.

*Background:* Although many small nutrients enter eukaryotic cells either through passive diffusion or via specialized transport channels in the cell membrane, some components gain cell entry through "bulk" transport. Phagocytosis is one type of bulk transport, which involves the uptake of larger extracellular components such as whole cells and large polar or fully charged molecules like multi-subunit protein complexes. Through generation of an intracellular vesicle, the extracellular component(s) gain entry to the cell's endomembrane system. This process occurs through the formation of a vesicle, which forms from the creation of an invagination of the cell's plasma membrane [1].

*Scenario:* Imagine that your classroom is a macrophage cell (an immune cell that is found in animals). Macrophages are called "professional phagocytes" because they are cells that function specifically to eliminate infectious bacterial cells from the tissues through the process of phagocytosis. Imagine you are a macrophage that has just encountered a *Streptococcus* bacterium in the throat of a human. Your task is to work together with your associated organelle partners to devour the bacterium, break it down into its basic macromolecule monomers, and recycle these components to be used in cell function.

### *Activity Instructions*

*Part 1: Strategize the Cellular Process*

For each of the following steps, record your responses on the provided white board (or as your instructor advises).

1. Discuss the functions of your specific organelle and what role your organelle will play in this scenario.
2. Discuss what other organelles or cell structures your group will interact with to complete the task in the scenario.
3. Construct a diagram of the sequence of events that must occur to complete the given task.
4. As a class, confirm with your instructor that the sequence of events is correct and modify your diagram with any changes. Do not go on to Step 5 until you are given permission by instructor.

*Part 2: Model Phagocytosis, Breakdown, and Recycling of* Streptococcus *Bacterium*

5. Assuming the walls of the classroom are the boundaries of the cell, choose the appropriate location within the "cell" for your organelle and position yourself there.
6. Using props (or yourselves) carry out the scenario from beginning to end. At each step, the members of the organelle must act out the function of the organelle and explain the details of the process to the class.

## *Questions*

1. Given what you know about the differences in animal and plant cell structures, would this type of bulk transport occur in plants? Why or why not?

2. What types of cellular structures are used to transport "bulk" items (i.e. nutrients, water, large organic carbon molecules?) What is the name of the specific structures that function as channels between plant cells?

3. Because of the differences in cell boundary structure between plants and animals, plants must maintain a positive intracellular pressure to increase "turgidity." Identify the organelle that maintains intracellular pressure in plants. Identify the substance it stores and explain why this cellular pressure must be maintained for proper cell function.

## *Reference*

[1] Urry, L.A., *et al*. 2017. *Campbell Biology*, 11th ed. Pearson Education, Inc.