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Learning about Photosynthesis through Interactive Modeling and Simulations

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Contemporary undergraduate biology instruction has undergone a paradigm shift from rote memorization and isolated examination of biological mechanisms presented in an artificial, linear fashion to a more robust, systems-based study of complex, interconnected processes. In systems biology, the use of modeling and simulation emphasizes higher-order cognitive skills, positioning students to be critical and reflective thinkers proficient in problem solving and effective communication. While the value of systems biology analysis in an undergraduate setting is well-recognized, implementation, particularly in large-enrollment introductory biology courses, has proven difficult. Cell Collective (https://learn.cellcollective.org) is an accessible (no prior computational experience required) web-based platform for creating and simulating dynamic models of biological processes. In this lesson, students will use Cell Collective to investigate the process of photosynthesis. The investigations are suitable for introductory and intermediate classes, and are readily completed in either an in-class or homework setting.

Keywords: photosynthesis, biology, modeling, inquiry-based learning

Introduction

This computer-based laboratory activity is designed to introduce photosynthesis to freshmen biology majors through modeling and simulations using a systems biology approach. The activity should be implemented concurrently with the fundamental principles of photosynthesis. Divided into two scaffolded investigations, the lesson guides students to explore the processes of photosynthesis. In the first investigation, students learn how the light-dependent reactions and the Calvin Cycle work together to convert light energy into chemical energy. The second investigation explores the impact on photosynthesis when external stimuli (such as sunlight) change. Throughout this computer-based lesson, students explore photosynthesis by engaging in the iterative process of making predictions, observations, and explaining their reasoning.

Learning Goals

- Students will describe the process of photosynthesis and its inputs and outputs.
- Students will explain the impacts of various environmental conditions on photosynthetic processes.
- Students will create and simulate a model of photosynthesis.

Learning Objectives

- Students will describe the two steps of photosynthesis and explain how they are related.
- Students will explain why ATP and NADPH are only made in the presence of light.

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- Students will identify the origins of carbon and oxygen in the products of photosynthesis.
- Students will describe the role of stomata in photosynthesis.
- Students will describe the ways glucose produced during photosynthesis are used within the plant.

Intended Audience

This lesson is most suited for introductory biology undergraduate courses in either a laboratory setting or as a homework or in-class activity in a lecture course. Versions of this lesson have been implemented in an introductory organismal biology course for biology majors as both a laboratory activity and a homework assignment in a lecture course at a large research-intensive university.

Required Learning Time

This lesson, including assessment, takes an average of 90 minutes to complete. If less class/lab time is available, parts can be assigned as homework.

Prerequisite Student Knowledge

While some basic understanding of photosynthesis may be helpful, the lesson is designed to be independent whereby students are able to successfully complete it without prior knowledge of the topic.

Prerequisite Teacher Knowledge

Instructors should be familiar with photosynthetic processes and be able to explain the fates of various inputs and outputs of photosynthesis within the plant. Instructors should also become familiar with the simulation lesson in Cell Collective.

Student Outline

Objectives

- Describe the two parts (the light dependent reaction and the Calvin Cycle) of photosynthesis and explain how they are related.
- Explain why ATP and NADPH are only made in the presence of light.
- Identify the inputs and products of photosynthesis.
- Describe the role of stomata in photosynthesis.
- Describe the ways glucose produced during photosynthesis are used within the plant.

Introduction

Life on this planet is dependent upon the photosynthesis. With few exceptions, all terrestrial and aquatic plants photosynthesize, from single-celled algae to towering redwood trees. Much more than the simple equation memorized in grade school — CO2 + sunlight → sugar + O2 — the process of photosynthesis involves a coordinated and complex orchestration of interdependent reactions to make inorganic carbon available to heterotrophs and provide the oxygen we require for life. Today, we will be exploring the processes of photosynthesis by building a model in the web-based platform, Cell Collective. Through two investigations, you will conduct experiments to observe how oxygen, carbon dioxide, and sunlight work together to convert light energy to chemical energy. In this activity, you will explore what happens to the production of energy at night and why your houseplants die when you forget to water them.

Access the Modeling and Simulation Lesson: "Modeling Light and Dark Reactions in Photosynthesis"

1. Go to learn.cellcollective.org
2. Sign up and/or login to Cell Collective
3. Once logged in, select the card "Modeling Light and Dark Reactions in Photosynthesis"
4. Click "Add to my learning" from the Overview page
5. Click "Learning Activities" in the top menu bar to begin the lesson
6. Click the "save" icon on the upper-left corner of the page frequently, to track your work.
7. Once the lesson has been saved, it can be re-accessed by navigating to "My Learning" from the main logged in home page.

Materials

Each student (or a working group) should have a computer with connection to the Internet, and installed the most recent version of the Chromium or Firefox browsers.

Notes for the Instructor

While students have the ability to answer integrated questions throughout the lesson, we are still working on the ability to export the data and supply it on-demand to instructors. Thus, it is recommended that instructors use Google Forms to collect student answers. Instructors can gain access to these Google Forms by contacting support@cellcollective.org. Upon request we can also provide instructor answer keys, where applicable.

Solutions for Common Student Issues

- If the model is not editable, make sure students are at https://learn.cellcollective.org. Https://cellcollective.org is for research purposes and students will not be able to complete the learning activities.
- Make sure students are adding the lesson to ‘My Learning’ - not adding to ‘My Learning’ can result in students not being able to save their work.

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About the Authors

Gretchen King is a Postdoctoral scholar at the University of Lincoln-Nebraska. Her research focuses on understanding how undergraduates reason about biological models. She is also interested in understanding the role of metacognition in students’ learning in biology. Dr. King earned her PhD in Science Education from the University of Georgia.

Resa Helikar oversees the product development of the technology, Cell Collective. Ms. Helikar received her undergraduate degree in Bioinformatics and MBA from the University of Nebraska. Her interests lie in technology-driven education and product development.

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Tomas Helikar is an Associate Professor in the Department of Biochemistry at the University of Nebraska at Lincoln (UNL). Dr. Helikar's research centers around the development of computational biology methods. He utilizes computational modeling and simulations to understand the dynamical nature of biological processes, as well as interactive pedagogical methods to teach about biological systems to life sciences students. Dr. Helikar develops and teaches courses on computational biology and modeling. Dr. Helikar's work is currently being supported by several NSF grants, an NIH grant, and Google, Inc. In 2016, Dr. Helikar received UNL's Dinsdale Award for Excellence in Research, Teaching, and Service.

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