**The Stomata Lab**

What the past can tell us about our future – using fossil and modern plants to model atmospheric carbon dioxide.

# INSTRUCTOR GUIDE

# Module Description: This module guides students through building a mathematical model of a biological relationship, evaluating the model, improving it, and then using the model. The biological context is global climate change and atmospheric CO2 levels today and in the deep past. The most rapid period of warming in Earth’s geologic history, until today, was during the Paleocene Eocene Thermal Maximum, 56 million years ago. Understanding this period is important to preparing for our future. In this lab, students use leaf stomata counts to estimate the atmospheric CO2 levels during this event. Students will collect data from samples used in published and ongoing research at the Smithsonian National Museum of Natural History and the Smithsonian Environmental Research Center. Students will use a regression to establish the mathematical relationship and evaluate it using the goodness of fit statistic, R2, the coefficient of determination. They will also evaluate the biological meaning of the model. The module is designed to be implemented in a two-hour laboratory session, but it can easily be broken up into smaller sessions.

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# Quantitative Competencies and Learning Objectives

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| Quantitative Competency | Learning Objective | Activity |
| Comp 3b, 4b | Develop a mathematical model of the relationship between atmospheric CO2 and the number of stomata on a leaf (Stomata Index). | Herbarium and Modern dataExperimental Data |
| Comp 2, 3b, 4b | Evaluate the model graphically, statistically, and biologically | Herbarium and Modern dataExperimental Data |
| Comp 4c | Use the model to estimate CO2 levels in the distant past. | Using the Model: Fossil Data |

# Quantitative-Reasoning Competency Description

The Quantitative Competencies for the NIQB-IUSE Project are adapted from the Association of American Medical College’s and Howard Hughes Medical Institute’s *Scientific Foundations for Future Physicians* (2009), which can be accessed at: <https://www.aamc.org/download/271072/data/scientificfoundationsforfuturephysicians.pdf>

Competency 2: Interpret data sets and communicate those interpretations using visual and other appropriate tools [SFFP 2]

 Goals:

1. Interpret appropriate graphical representations of data, using (but not limited to):
	* frequency histogram
	* scatter plot
	* bar graph
	* box and whisker
	* semi-log graphs
	* double reciprocal graph
	* pie chart
2. Create an appropriate graphical representation of data, such as those described in goal a. above
3. Identify different components of graphs (*e.g.*, slopes, rates of change, asymptotes, intercepts, error bars)

Competency 3: Demonstrate proficiency with statistical analyses and make inferences [SFFP 3]

 Goals:

1. Apply statistical analyses to biological data sets (e.g., Chi-square and t-Test) and interpret the findings

Competency 4: Demonstrate facility with mathematical models of biological systems and be able to make inferences about natural phenomena [SFFP 5]

 Goals:

1. Identify the relationship between the dependent and independent variables in a model
2. Predict biological phenomena using mathematical models, for example: exponential population, Nernst equation, estimating protein concentrations, amplification of signaling pathways or iterative models.

# Target Student Population

# This module is intended for first-year biology majors in an introductory biology course. This activity assumes:

* Students have been exposed to photosynthesis and stomata.
* Students have been exposed to the statistical idea of significance. This module uses it, it does not teach it.
* Students have a basic understanding of reading and interpreting graphs.

# Module Characteristics

Mathematical/Statistical Concepts Covered:

* Regression
* R2 (coefficient of determination) is a goodness of fit statistic
* Hypothesis testing

In-class Activities:

* Data collection (counting stomata), Calculating Stomata Indices
* Interpreting Graphs
* Using regression and R2 to interpret and evaluate a model.

Components of Module:

* Preparatory assignment on regression and R2 goodness of fit
* In-class worksheet
* Data collection sheets
* Guidelines for implementation

Quantitative Skills Required:

* Basic arithmetic
* Logical reasoning
* Graph/Data Interpretation

**Pre-laboratory Exercises List of Files**

Stomata PreWork.docx

**Data Collection Sheets for the Module**

Zip file of Data collection Sheets

 Includes: Data collection sheets for students and the Answer Keys

**Guidelines for Implementation**

Prior to the module assign the prework “Linear Regressions”

For the module, have students break up into groups, ideally 3 students each.

Visuals – consider a PowerPoint slide or two on stomata if students do not share a similar educational background.

Looking at actual stomata (not images) – Using leaves from the kalanchoe plant or some other thick leaved plant, students can peel off the cuticle, make a wet mount, and observe stomata under a microscope. If you start the lab in this way, you connect what the students will be doing in the lab (with digital images) to a physical plant that they have just touched and manipulated.

Data – Spend time on data collection training (counting the stomata). We found that after each of the first three images, showing the class the key of that image and having the students evaluate their data, really improved their data. Time up front will save you time on the backend. Think about laminating the data sheets so students can mark the stomata with a dry erase marker, or use a tool on the computer to mark the digital image.

Statistics – The following are the *p*-values from ANOVA analyses run on the data provided in the Data Collection Keys.

* + Herbarium (linear regression)
		- *R*2 = 0.64
		- *p*-value = 0.005
		- Or you can present it as p-value < 0.01
	+ Experimental (power regression)
		- *R*2 = 0.76
		- *p*-value = 9.87E-07
		- Or you can present it as p-value < 0.001

References

Barclay, R. S., & Wing, S. L. (2016). Improving the Ginkgo CO2 barometer: Implications for the early Cenozoic atmosphere. *Earth & Planetary Science Letters*, 439, 158–171.

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