Manduca Growth Experiment

Ask a Biologist activity for the classroom and home

Photo by Art Woods

Virtual and laboratory explorations into the effects of temperature on the growth of an organism

This is an educator and student guide to be used with the following online resource:

http://askabiologist.asu.edu/experiments/manduca

Manduca **growth guide** http://askabiologist.asu.edu/experiments/manduca

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Introduction

Introduction to the *Manduca* Growth Experiment

Global climate change is something that you have probably heard about. The temperature on Earth is always changing - it changes daily, seasonally, and over longer time scales. It impacts not only the weather on Earth, but the climate as well. Scientists want to know how these changes are going to affect life on earth. How will organisms and communities respond to these changes? Will changes in temperature cause these animals to shrink or get larger?

To study how temperature can affect how an animal grows, Arizona State University's Ask a Biologist website has teamed up with the scientists in the laboratory of Dr.'s Jon Harrison and John VandenBrooks. Together, they started an experiment to see how warm and cool environments affect the growth of the *Manduca* caterpillar.

The Manduca growth experiment is designed to help science students to uncover the impact that temperature has on the size and growth rate of an organism. It is broken up into three options, the quick virtual lab, the full virtual lab, and growing your own Manduca at a warm and cool temperature.

> **Quick Virtual Lab:** This tool can be used as a way to quickly gather data on one *Manduca* grown in each of two different temperature settings and explore the effect of temperature on growth and size in single animals.

> **Full Virtual Lab**: This tool can be used as an alternative to growing and measuring live *Manduca* in the classroom. Students can measure the mass and length of several caterpillars from both temperature settings, generate graphs of the data, complete a statistical analysis to determine significance of their results, and explore the reasons behind the changes due to temperature.

> **Do it Yourself Lab**: This tool can be used as a long-term experiment lasting up to 35 days. Students can explore the impact of temperature on size and growth rate by raising their own *Manduca* from egg to emerging moth.   Here, students are able to do everything in the virtual lab, but with their own live caterpillars!

This teacher resource packet contains teacher instructions, student handouts, a sample lesson plan, and background information needed to assist middle school and high school students in successfully exploring how temperature changes can impact the size and growth of organisms.

The Virtual *Manduca* Growth Experiments

Quick Virtual Lab

The Quick Virtual Lab has been designed to be used by middle school or high school students as a way to quickly gather data on an individual *Manduca* grown in two different temperature settings.

Objectives:

- Generate a line graph to determine growth rate and maximum size
- Interpret graphs to determine how temperature impacts mass and length
- Determine how temperature can affect growth rate of an organism
- Explain why temperature may affect growth rate
- Generate a hypothesis
- Evaluate a hypothesis based on the analysis of data and the interpretation of background information on *Manduca sexta* and animal growth
- Apply the interpretation of the data from this experiment to Manduca in a natural environment that is demonstrating a warming trend.

Steps for doing the quick virtual lab

1. Have students generate a hypothesis regarding how temperature will affect the growth and size of *Manduca* over time.   Based on their hypothesis, have them make some predictions about what they would expect to see in the *Manduca* grown at the warm and cool temperatures.
2. Start with the *Manduca* Grown at 20°C. Set the Day to 01 and click Apply.
3. Students should record the mass in grams of the *Manduca* for day 1 in their data table from the results section. The mass can be found in the green area at the top of each picture.

Manduca 01 (Lab 20°C), Day 1
Mass in grams (g): 0.001661
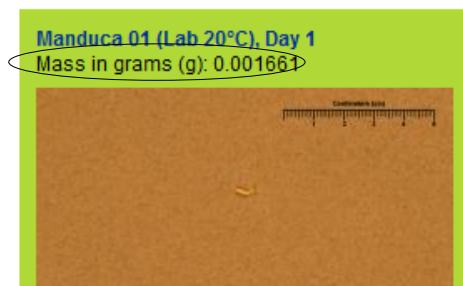
4. To measure length, students should first click on the picture to magnify it. They can measure the length by clicking on one end of the Manduca caterpillar. Then, have them click on five points along the rest of the Manduca with the last point being the opposite end of the Manduca. The students should record the length in their data table from the results section.
5. Students should now repeat procedures 2-4 for all days for this *Manduca*
6. Students should then do the same for the 30°C *Manduca* by repeating steps 1-5.
7. For each of the *Manduca,* have students plot two line graphs: one for length vs. days and one for mass vs. days using the included graph paper below, Microsoft Excel, or the link on the website.
8. Have students look at their data tables and find the maximal mass and longest length, and the day at which both were reached for each *Manduca*. They should circle these numbers on their data tables.
9. Using the graphs that are produced, have the students discuss and decide how to calculate growth rate*,* then calculate the growth rates for each *Manduca* and record in their data tables. ***Hint:*** *good way to calculate growth rate is to subtract initial mass from maximum mass and divide by the number of days to achieve maximal mass.*
10. Encourage students to interpret and analyze their data using the following questions. You may find that giving students access to the background information included in this resource packet will help them with the interpretation of the data
    a. Look at the growth curves from each graph. Do you think this is the best way to determine the growth rate? Why or why not? What are some other ways that you could measure growth rate?
    b. Which caterpillar grew faster, the one at the cold or warm temperature? Why do you think that happened?
    c. Were animals larger in the cold or warm temperature? Is your answer the same whether you use length or mass to determine size?
    d. Would you change your hypothesis based on your observations? Why or why not? How much data would you need to be sure?
    e. Why do you think that cold and warm temperatures caused *Manduca* to grow differently?
    f. If temperatures are changing globally, how do you think this will affect *Manduca* in the wild and the plants it feeds on?

Name:_____

Date:_____

Period:_____

Student Handout-Quick Virtual Lab

Question: How will temperature affect the growth of *Manduca* over time?

Hypothesis:

Predictions: Based on your hypothesis, predict what you think will happen to the *Manduca* at each temperature.

Methods:

1. Start with the *Manduca* Grown at 20°C. Set the Day to 01 and click Apply.
2. Students should record the mass in grams of the *Manduca* for day 1 in their data table from the results section. The mass can be found in the green area at the top of each picture.
3. To measure length, first click on the picture to magnify it. You can measure the length by clicking on one end of the Manduca caterpillar. Then, click on five points along the rest of the Manduca with the last point being the opposite end of the Manduca.   Record the length in the results data table.
4. Now repeat steps 2-4 for all days for this *Manduca*
5. Make the same measurements for the 30°C *Manduca* by repeating steps 1-5.
6. For each of the *Manduca,* plot two line graphs: one for length vs. days and one for mass vs. days using the included graph paper below, Microsoft Excel, or the link on the website.
7. Look at your data table and find the maximal mass and longest length, and the day at which both were reached for each *Manduca*. Circle these numbers on your data table.
8. Using the graphs that are produced, determine how to calculate growth rate. Write what you think in the space below:
9. Calculate the growth rates for each *Manduca*, and record in your data table.

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Results:

Manduca grown at 20°C Growth Rate=			Manduca grown at 30°C Growth Rate=		
Day #	Mass(g)	Length(cm)	Day #	Mass(g)	Length(cm)

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Analysis of Data:

1. Look at the growth curves from each graph. Do you think this is the best way to determine growth rate? Why or why not? What are some other ways that you could measure growth rate?

2. Which caterpillar grew faster, the one at the cold or warm temperature? Why do you think that happened?

3. Were animals larger in the cold or warm temperature? Is your answer the same whether you use length or mass to determine size?

4. Would you change your hypothesis based on your observations? Why or why not?

5. Why do you think that cold and warm temperatures caused the *Manduca* to grow differently?

6. If temperatures are changing globally, how do you think this will affect the *Manduca* in the wild and the plants it feeds on?
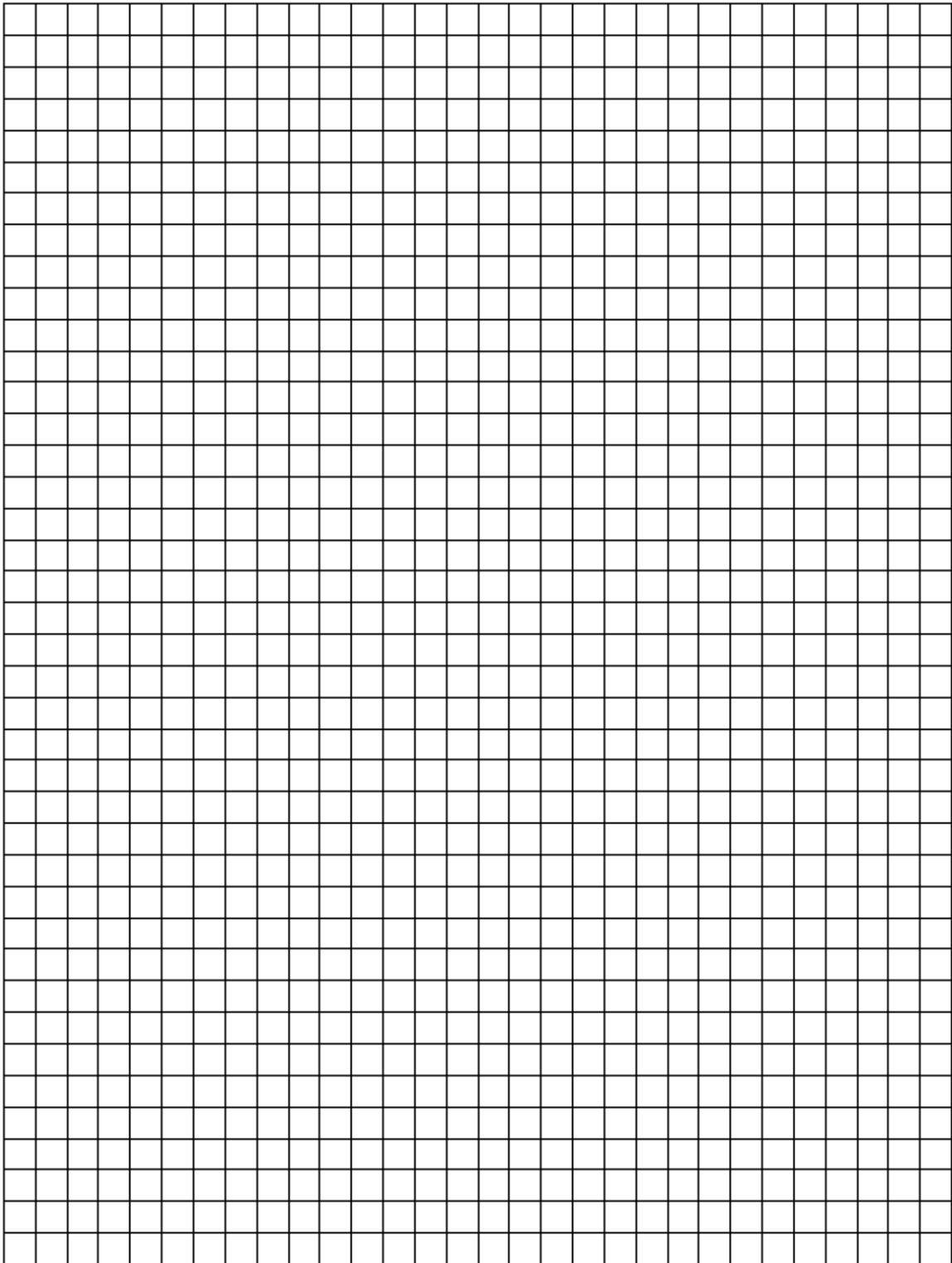
Full Virtual Lab

The full virtual lab is intended to be used by high school students as an alternative to growing and measuring live *Manduca* in the classroom. Students will measure the mass and length of several organisms from both the warm and cool environments, generate a graph of the data, complete a statistical analysis of the data to determine if there are real differences between treatment groups, and develop explanations for their observations.

Objectives:

- Generate a line graph to determine growth rate and maximum body size
- Interpret graphs to determine how temperature impacts mass and length
- Calculate growth rate, mean, and standard deviation using experimental data on mass and length
- Determine how temperature can affect growth rate of an organism
- Explain why temperature may affect growth rate
- Generate a hypothesis
- Evaluate a hypothesis based on the analysis of data and the interpretation of background information on *Manduca sexta* and animal growth
- Apply the interpretation of the data from this experiment to Manduca in a natural environment that is demonstrating a warming trend.
- Analyze the significance of experimental data using graphs of mean and standard deviation

Steps for doing the full virtual lab

1. Have students generate a hypothesis regarding how temperature will affect the growth and size of *Manduca* over time.   Based on their hypothesis, have them make some predictions about what they would expect to see in the *Manduca* grown at the warm and cool temperatures.
2. Assign each pair of students to one *Manduca* grown for both the warm and cool environment.
3. Have students click on their assigned *Manduca* from the 20°C temperature, and day 01, then click Apply.

4. Students should record the mass in grams of their *Manduca* for day 1 in their data table from the results section. The mass can be found in the green area at the top of each picture.

Manduca 01 (Lab 20°C), Day 1
Mass in grams (g): 0.001661
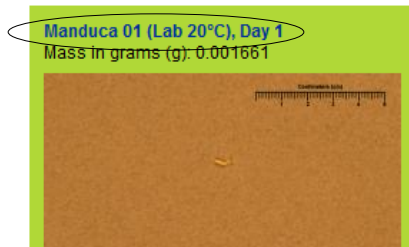
5. To measure length, students should first click on the picture to magnify it. They can measure the length by clicking on one end of the Manduca caterpillar. Then, have them click on five points along the rest of the Manduca with the last point being the opposite end of the Manduca. The students should record the length in their data table from the results section.

6. Students should now repeat procedures 2-4 for all days for this *Manduca*

7. Repeat steps 2-6 for their assigned *Manduca* from the 30°C temperature.

   *Note: there is some data that is missing from the data set. Discuss with students why data may not have been gathered on one or more days (maybe the experimenter was ill or couldn't come into the lab to collect data). Also discuss the impact this may or may not have on the overall experimental data.

8. Have the students create a line graph of length vs. days and mass vs. days for their assigned *Manducas* using the Microsoft excel graphing link on the full virtual lab website or Microsoft Excel on their own computers.

9. Have students look at their data tables and find the maximal mass and longest length, and the day at which both were reached for their assigned *Manducas*. They should circle these numbers on their data tables.

10. Using the excel graphs that are produced, have the students discuss and decide how to calculate growth rate. *Hint: good way to calculate growth rate is to subtract initial mass from maximum mass and divide by the number of days to achieve maximal mass.*

11. Have students share their data to create one master data table containing the maximal mass, longest length, and growth rate for each individual. Calculate the mean values of the entire data set for maximum length, maximum mass, and growth rate at both temperatures using the following method:

   How to calculate mean

   1. Add up all the measured values for a given variable
   2. Divide by how many individuals there are

12. Have students calculate the standard deviation of the entire data set for longest length, maximal mass, and growth rate at both temperatures using the following method:

How to calculate standard deviation for a variable at a given condition

1. Calculate the mean for the variable you are analyzing
2. For each individual, determine the deviations for each of the numbers being analyzed for that variable.
   Example: longest length – mean length at that temperature = deviation
3. Square the deviations (multiply the deviation by itself)
4. Add up the squares of all the deviations
5. Divide the sum of the squares by the total number of individuals minus one
   Example: if you had 10 individuals, minus 1 is 9, so take the sum of the squares and divide it by 9
6. Take the square root of the answer from step # 5. This is the Standard Deviation

13. For each variable (longest length, maximal mass, and growth rate), have the students make two graphs using on their own computers, or using graph paper. The first graph plots each individual value (y-axis) vs. the two temperatures (x-axis). The second graph plots mean and standard deviation (y-axis) vs. the two temperatures (x-axis).

Example Graph 1: Individual values vs. condition – This is a plot of male and female student heights in one classroom.

Example Graph 2: Mean and standard deviation vs. condition-This is a plot of mean height and standard deviation for male and female students in one classroom
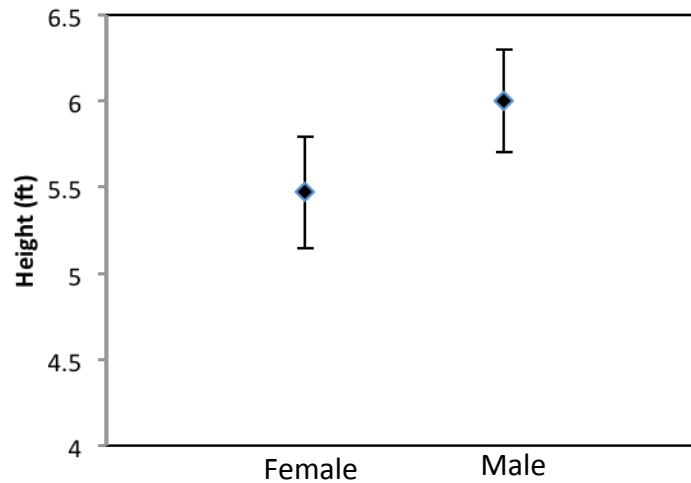
14. Have students visually compare the two graphs for each variable. **Ask them to determine if the values for the two temperatures overlap.**

Helpful Hints

One important point for the students to learn is that individuals, whether they are humans or caterpillars, are different. This makes it much more complicated to understand the world scientifically. Here we introduce some basic concepts related to understanding how scientists cope with such variation in interpreting the world.

Standard deviation is a measure of how tightly clumped the values are. Notice that the spread of the individual points correlates with the size of the standard deviation. If all the points are clumped closely around the mean, the standard deviation should be small; if the points are widely spread, the standard deviation will be large.

Another important point is that variation among individuals can make it challenging to determine whether differences in mean values are "real", or just represent random variation associated with the fact that different individuals are in the two treatment groups. If the variation around the mean is small and the effect of the treatment is large, this is not such a concern. For example, for some variables such as growth rate, the students may notice that there is little or no

overlap between the points for the two temperatures. Under these circumstances, visual inspection of the distribution of points can make us confident that the effect of temperature on that variable is strong and "real".

On the other hand, if there is a lot of overlap in the values for the two groups, then it is more challenging to determine if this is a "real" effect (this will be true for maximal size). To answer whether the difference in the means is real or just random variation, a statistical test must be used. Students can easily do a statistical test of whether variables differ statistically between the two temperature groups using a Student's t test. There are many sites on the internet that explain how to perform this test, and how to interpret the probabilities. Alternatively, they could just learn that it is more likely that the effect is "real" if the differences in the means are larger, if the standard deviations are smaller, and sample sizes are larger.

15. Encourage students to interpret and analyze their data using the following questions. You may find that giving students access to the articles and websites in the background information of this resource packet will help them in the interpretation of the data:
    a. Look at the growth curves from each graph. Do you think is the best way to determine the growth rate? Why or why not? What are some other ways that you could measure growth rate?
    b. Which caterpillars grew faster, the ones at the cold or warm temperature? Why do you think that happened? How sure are you of your answer, given the variation in the *Manducas* grown at each temperature?
    c. Were animals larger in the cold or warm? Is your answer the same whether you use length or mass to determine size?
    d. Would you change your hypothesis based on your observations? Why or why not? Are you sure-are more data needed to be sure?
    e. Why do you think that cold and warm temperatures caused the *Manduca* to grow differently?
    f. If temperatures are changing globally, how do you think this will affect the *Manduca* in the wild and the plants it feeds on?

Name:_____

Date:_____

Period:_____

Student Handout-Full Virtual Lab

Question: How will temperature affect the growth of *Manduca* over time?

Hypothesis:

Predictions: Based on your hypothesis, predict what you think will happen to the *Manduca* at each temperature.

Methods:

1. Click on your assigned *Manduca* from the 20°C temperature, and day 01, then click Apply.
2. Record the mass in grams of your *Manduca* for day 1 in the results data table. The mass can be found in the green area at the top of each picture.
3. To measure length, first click on the picture to magnify it. You can measure the length by clicking on one end of the Manduca caterpillar. Then, click on five points along the rest of the Manduca with the last point being the opposite end of the Manduca. Record the length in the results data table.
4. Repeat procedures 2-3 for all days for this *Manduca*
5. Repeat steps 2-4 for your assigned *Manduca* from the 30°C temperature.
6. Create a line graph of length vs. days and mass vs. days for your assigned *Manducas* using the Microsoft excel graphing link on the full virtual lab website or Microsoft excel on your own computer.
7. Look at your data table and graphs and find the maximal mass and longest length, and the day at which both were reached for your assigned *Manducas*. Circle these values on your results data table.
8. Using the graphs you produced, determine how you could calculate growth rate. Write what you think on the space below:Calculate the growth rate for your *Manduca*, and record in the appropriate Analysis Data Table.

9. As a class, share the maximal mass, longest length, and growth rate for each of the *Manduca* at each temperature. Record these values in the Analysis Data Tables.
10. Calculate the mean values of the entire data set for maximum length, maximal mass, and growth rate at both temperatures using the following method. Record all values in the Analysis Data Tables.

    <u>How to calculate mean</u>

    1. Add up all the measured values for a given variable

    2. Divide by how many individuals there are

11. Calculate the standard deviation of the entire data set for longest length, maximal mass, and growth rate at both temperatures using the following method. Record all values in the Analysis Data Tables.

    <u>How to calculate standard deviation for a variable at a given condition</u>
    1. Calculate the mean for the variable you are analyzing
    2. For each individual, determine the deviations for each of the numbers being analyzed for that variable.
        <u>Example:</u> longest length – mean length at that temperature = deviation
    3. Square the deviations (multiply the deviation by itself)
    4. Add up the squares of all the deviations
    5. Divide the sum of the squares by the total number of individuals minus one
        <u>Example:</u> if you had 10 individuals, minus 1 is 9, so take the sum of the squares and divide it by 9
    6. Take the square root of the answer from step # 5. This is the Standard Deviation

12. For each variable (longest length, maximal mass, and growth rate), make two graphs using your own computer or graph paper. The first graph will plot each individual value of length, mass, and growth rate (y-axis) vs. the two temperatures (x-axis). The second graph will plot mean and standard deviation (y-axis) vs. the two temperatures (x-axis)

Example Graph 1: Individual values vs. condition – This is a plot of male and female student heights in one classroom.
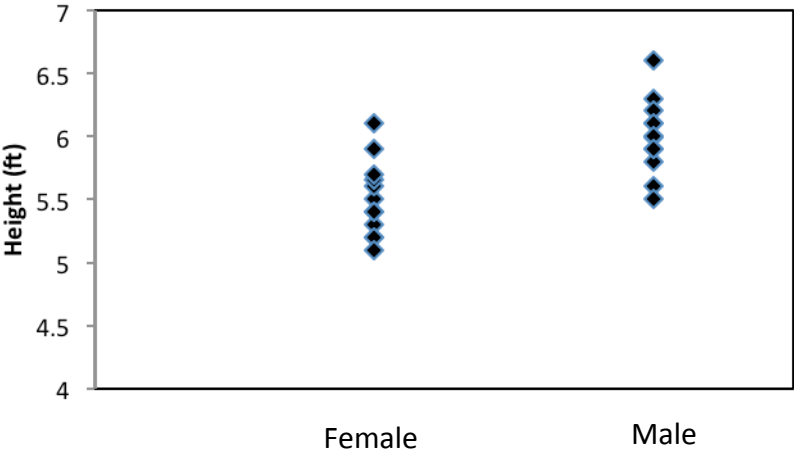
Example Graph 2: Mean and standard deviation vs. condition-This is a plot of mean height and standard deviation for male and female students in one classroom

13. Look at each of the graphs produced, and compare them. Are there any values (length, mass, growth rate, mean, standard deviation) that overlap for the two temperatures? If values from the two different temperatures do overlap, what do you think that means? If values from the two different temperatures do not overlap, what do you think that means?

Results Data Table:

Manduca grown at 20°C				Manduca grown at 30°C			
Day #	Manduca #	Mass(g)	Length(cm)	Day #	Manduca #	Mass(g)	Length(cm)

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Analysis Data Tables:

Manduca #	Maximal Length (cm)	Maximal Mass(g)	Growth Rate	Deviation From Mean	Deviation squared
				Manduca Grown at 20°C	
	Mean =	Mean =	Mean =	Sum of deviation= Sum/total # of #'s-1= Standard Deviation=	

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Manduca Grown at 30°C					
Manduca #	Maximal Length (cm)	Maximal Mass(g)	Growth Rate	Deviation From Mean	Deviation squared
	Mean =	Mean =	Mean =	Sum of deviation= Sum/total # of #'s-1= Standard Deviation=	

Analysis of Data:

1. Look at the growth curves from each graph. Do you think this is the best way to determine the growth rate? Why or why not? What are some other ways that you could measure growth rate?

2.Which caterpillars grew faster, the ones at the cold or warm temperature? Why do you think that happened? How sure are you of your answer, given the variation in the *Manducas* grown at each temperature?

3.Were animals larger in the cold or warm? Is your answer the same whether you use length or mass to determine size?

4.Would you change your hypothesis based on your observations? Why or why not? How much data is needed to be sure?

5.Why do you think that cold and warm temperatures caused the *Manduca* to grow differently?

6.If temperatures are changing globally, how do you think this will affect the *Manduca* in the wild and the plants it feeds on?

Do it Yourself *Manduca* Growth Experiment

Objectives

- Generate a line graph to determine rates of change
- Interpret graphs to determine how temperature impacts mass and length
- Explain how growth rate is determined
- Calculate growth rate, mean, and standard deviation using experimental data on mass and length
- Determine how temperature can affect growth rate of an organism
- Explain why temperature may affect growth rate
- Generate a hypothesis
- Evaluate a hypothesis based on the analysis of data and the interpretation of background information on *Manduca sexta* and animal growth
- Apply the interpretation of the data from this experiment to Manduca in a natural environment that is demonstrating a warming trend.
- Analyze the significance of experimental data using graphs of mean and standard deviation

Materials:

- 2 cardboard boxes 16in x 16in x 6.5in (40.6cm x 40.6cm x 16.5cm)
- A 1 oz cup and 1 oz lid for every insect (can be purchased from restaurant supply or party stores)
- A 20 oz cup with a lid for every insect (can be purchased from restaurant supply or party stores)
- Two thermometers
- A scale or balance to record mass
- A string of incandescent holiday lights (large bulbs)
- Aluminum foil or plastic wrap
- Angle compass
- Gloves
- Paper towels
- Permanent marker
- *Manduca sexta* eggs (item # 143880 from Carolina Biological Supply www.carolina.com) 20-50 eggs per class
- Sticks or pencils for pupation
- Hamster bedding/wood shavings

- Artificial diet (item # 143908 from Carolina Biological Supply www.carolina.com)
- Scissors
- Soft forceps (item # P-011 from entomopro.com)
- Soft bristle brush (a small soft-bristled paint brush, item # 6020-0100 from www.gordonbrush.com, or purchase from an art supply store)

Methods:

Setting up the boxes to be used for the warm and room temperature environments:

1. Making sure the lights are not plugged in, unscrew all of the bulbs from the strip of Holiday lights.
2. Using an angle compass, trace a circle along the inside bottom of the box (the radius should be in the center and extend to the wall of the box)

3. Cut a hole that is large enough to fit two of the holiday light sockets in the center of the circle you have drawn on the bottom of the box. Insert the two holiday light sockets into the bottom of the box. Screw the bulbs back onto each of the two light sockets that are inside of the box. **Make sure no part of the bulb itself is touching any part of the box to prevent all risk of fire. This can be done by either lining the bottom of the box with aluminum foil, or by putting a porcelain plate or other non-combustible material under the bulbs.**

4. Repeat these steps for additional warm temperature boxes that may be needed, and lay the boxes side by side so the holiday lights can be strung in a line underneath them. In general, one warm temperature box will be sufficient for each class of students.
5. For the room temperature box, no manipulation of the box is necessary.

Calibrating the warm environment box:

1. Place a thermometer in the warm temperature box anywhere along where the circle was drawn.
2. Close the lid of the box, and plug the lights in. Wait 2 hours, open the box and record the temperature reading. This is the temperature the *Manduca* will be growing in for the warm temperature environment. This should be near 30°C. If it's not close to 30°C, add or remove light bulbs as needed.

Creating the artificial diet:

1. Mix 1 part dry artificial mix into 3 parts of water that has reached a boil in a beaker or other cooking container (directions should be included with the artificial diet).
2. Stir for 10 minutes while simmering.
3. Take off of the heat and spread over a large cake pan or cookie sheet. Cover with aluminum foil or plastic wrap and store in the refrigerator.

Setting up the *Manduca* containers:

1. Choose the number of *Manduca* containers you will need for each class of students. In general, two students can be in charge of the measurements for one *Manduca*. For an average class of 32 students, you would need 16 containers. Scoop a thumbnail amount of artificial diet into each 1 oz cup that will be used to begin growing the eggs.
2. Use a soft forceps to place 1 egg in each 1 oz cup on top of the food.
3. Puncture each lid for the 1 oz cups 2-3 times with a thumbtack to allow for air flow.
4. Place a lid on each of the1 oz cups.
5. Use a permanent marker to label half of the cups "cool", then number each of the cups. Label the other half of the cups "warm", and number each of the cups.

6. Place the cups labeled "cool" in the room temperature box. These cups can be placed anywhere in the box because the temperature should be the same throughout the box.

7. Place the cups labeled "warm" in the box set up for the warm environment. Each cup should be placed along the circle drawn on the bottom of the box, so that each cup is equidistant from the heat source (the two light bulbs in the center).

8. Turn the lights on in the warm environment box. Make sure to keep these lights on for the remainder of the experiment.

On-going care of the *Manduca* larva:

- When a container looks dirty, remove the insect from the container using a soft forceps, and place them on the lid of the container. Use a paper towel and water to remove all feces and old food from the container. Dry the inside of the container with a paper towel, and scoop in the appropriate amount of food for that size of the cup. Place the insect back into the container with soft forceps, place the lid back onto the container, and place the container back into its appropriate box.

- When a *Manduca* has outgrown its 1 oz container, it is ready to be transferred to a 20 oz cup. Label the cup with a permanent marker so that it matches the label of the original

cup. Place a teaspoon of artificial diet into the larger cup, and then transfer the insect using the soft forceps. Make sure that the lid to the 20 oz cup has 4-6 holes punctured in it with a thumbtack to allow for air flow.

Collecting Data:

Check the containers daily to see if any of the insects have hatched. You should see them hatching after 3 days. Wait until the larva grows to approximately 1 cm to begin data collection

1. When a larva is ready to be measured take the cup out from the box and using a soft brush, transfer the larva from the cup to a balance to measure the mass and record the mass. After a larva has reached 300mg in mass, you can use the soft forceps to move them.
2. Measure the length by placing one end of the *Manduca* at the start of the ruler, then record in centimeters to the nearest millimeter how long the *Manduca* is. Record the length. As the *Manduca* grows, you may find that you need to use your fingers to gently lay the *Manduca* in a straight line along the ruler. Some students may feel more comfortable wearing gloves to handle the *Manduca* at this stage.
3. Return the larva to its cup and the cup to its appropriate temperature.
4. Repeat steps 1-3 every day up through pupation.
5. When the *Manduca* is ready to pupate (when it stops eating and begins "wandering" around its cup looking for a place to pupate), empty the food out of its 20 oz cup, and put 2-3 cm deep of pine shavings (hamster bedding), and a stick tilted on its side. Place the lid back on the container and place the cup back in the appropriate temperature.

6. When a moth emerges, leave it in the closed container, and place the container in a freezer over night to euthanize it, then place the moth on the balance the next day to measure its final mass. This is done to minimize the risks associated with releasing this live species into an environment that it may not be native to, and to assist with ease of the final measurements.

*You will find that the *Manduca* in the warm environment will complete their life cycle in a shorter time than it takes for the *Manduca* in the cold environment. When student

pairs can no longer collect data on their _Manduca_ because it has fully matured, a suggestion would be for that pair to join a pair from the cold environment to form a group of 4 to finish collecting data.

*If you have high mortality rates with the animals in your classroom, students can use the animals grown in the lab of Dr.'s Jon Harrison and John VandenBrooks using the same set-up described above. The information for these animals can be found under the DIY lab link on the _Manduca_ growth experiment website. To analyze these images, follow the instructions for the full virtual lab found <mark>on p.)</mark> *Note: there is some data that is missing from the data set. Discuss with students why data may not have been gathered on one or more days (maybe the experimenter was ill or couldn't come into the lab to collect data). Also discuss the impact this may or may not have on the overall experimental data.

<u>Analyzing the Data:</u>

1. For their assigned _Manduca_, have students create a line graph of length vs. days and mass vs. days using the Microsoft excel graphing link on the full virtual lab website or Microsoft excel on their own computers.
2. Have the students look at their data tables and find the maximal mass and longest length, and the day at which both were reached. They should circle these numbers on their results data tables.
3. Using the excel graphs that are produced, have the students discuss and decide how to calculate growth rate. *Hint: good way to calculate growth rate is to subtract initial mass from maximum mass and divide by the number of days to achieve maximal mass.*
4. Have students share their data to create one master data table containing the maximal mass, longest length, and growth rate for each individual. Calculate the mean values of the entire data set for maximum length, maximum mass, and growth rate at both temperatures using the following method:

    <u>How to calculate mean</u>

    1. Add up all the measured values for a given variable
    2. Divide by how many individuals there are

5. Have students calculate the standard deviation of the entire data set for longest length, maximal mass, and growth rate at both temperatures using the following method:

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How to calculate standard deviation for a variable at a given condition

1. Calculate the mean for the variable you are analyzing
2. For each individual, determine the deviations for each of the numbers being analyzed for that variable.

    Example: longest length – mean length at that temperature = deviation

3. Square the deviations (multiply the deviation by itself)
4. Add up the squares of all the deviations
5. Divide the sum of the squares by the total number of individuals minus one

    Example: if you had 10 individuals, minus 1 is 9, so take the sum of the squares and divide it by 9

6. Take the square root of the answer from step # 5. This is the Standard Deviation

6. For each variable (longest length, maximal mass, and growth rate), have the students make two graphs using their own computers or graph paper. The first graph plots each individual value (y-axis) vs. the two temperatures (x-axis). The second graph plots mean and standard deviation (y-axis) vs. the two temperatures (x-axis).

    Example Graph 1: Individual values vs. condition – This is a plot of male and female student heights in one classroom.
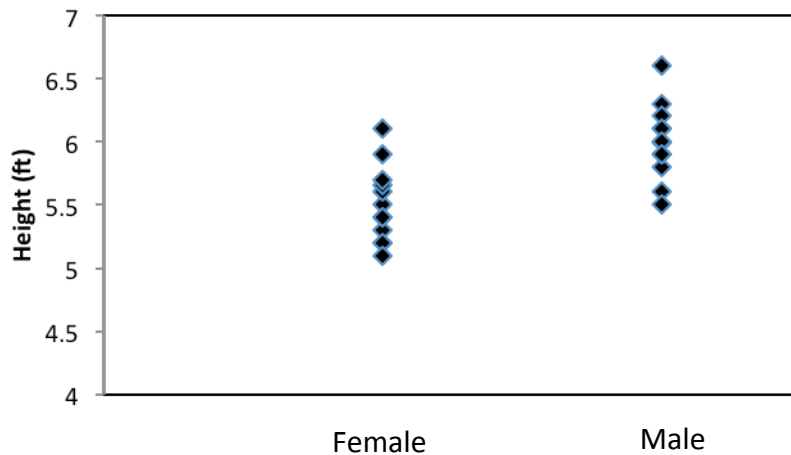
Example Graph 2: Mean and standard deviation vs. condition-This is a plot of mean height and standard deviation for male and female students in one classroom
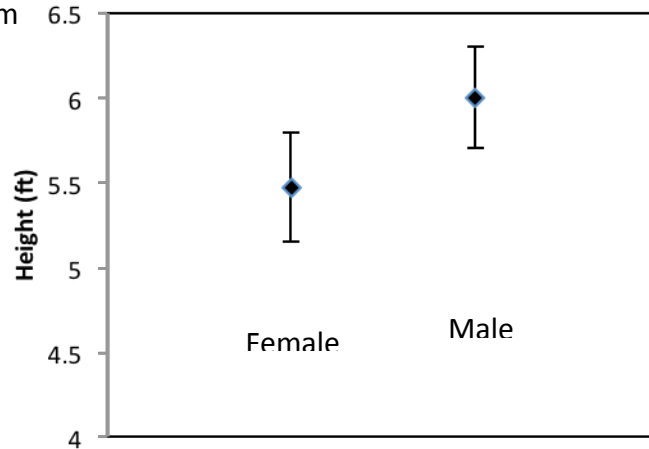
7. Have students visually compare the two graphs for each variable. **Ask them to determine if the values for the two temperature overlap.**

Helpful Hints:

One important point for the students to learn is that individuals, whether they are humans or caterpillars, are different. This makes it much more complicated to understand the world scientifically. Here we introduce some basic concepts related to understanding how scientists cope with such variation in interpreting the world.

Standard deviation is a measure of how tightly clumped the values are. Notice that the spread of the individual points correlates with the size of the standard deviation. If all the points are clumped closely around the mean, the standard deviation should be small; if the points are widely spread, the standard deviation will be large.

Another important point is that variation among individuals can make it challenging to determine whether differences in mean values are "real", or just represent random variation associated with the fact that different individuals are in the two treatment groups. If the variation around the mean is small and the effect of the treatment is large, this is not such a concern. For example, for some variables such as growth rate, the students may notice that there is little or no overlap between the points for the two temperatures. Under these circumstances,

visual inspection of the distribution of points can make us confident that the effect of temperature on that variable is strong and "real".

On the other hand, if there is a lot of overlap in the values for the two groups, then it is more challenging to determine if this is a "real" effect (this will be true for maximal size). To answer whether the difference in the means is real or just random variation, a statistical test must be used. Students can easily do a statistical test of whether variables differ statistically between the two temperature groups using a Student's t test. There are many sites on the internet that explain how to perform this test, and how to interpret the probabilities. Alternatively, they could just learn that it is more likely that the effect is "real" if the differences in the means are larger, if the standard deviations are smaller, and sample sizes are larger.

8. Encourage students to interpret and analyze their data using the following questions. You may find that giving students access to the articles and websites in the background information of this resource packet will help them in the interpretation of the data:

   a. Look at the growth curves from each graph. Do you think is the best way to determine the growth rate? Why or why not? What are some other ways that you could measure growth rate?

   b. Which caterpillars grew faster, the ones at the cold or warm temperature? Why do you think that happened? How sure are you of your answer, given the variation in the *Manducas* grown at each temperature?

   c. Were animals larger in the cold or warm? Is your answer the same whether you use length or mass to determine size?

   d. Would you change your hypothesis based on your observations? Why or why not? Are you sure-are more data needed to be sure?

   e. Why do you think that cold and warm temperatures caused the *Manduca* to grow differently?

   f. If temperatures are changing globally, how do you think this will affect the *Manduca* in the wild and the plants it feeds on?

Name:_____

Date:_____

Period:_____

Student Handout-Do it Yourself *Manduca* Growth Experiment

Question: How will temperature affect the growth of *Manduca* over time?

Hypothesis:

Predictions: Based on your hypothesis, predict what you think will happen to the *Manduca* at each temperature.

Methods:

1. Take a 1 oz cup, and use a permanent marker to label the *Manduca* # and temperature (cool or warm) that your *Manduca* will be at.
2. Scoop a thumbnail amount of artificial diet into a 1 oz cup
3. Use a soft forceps to place 1 egg in the 1 oz cup on top of the food.
4. Puncture the lid of your 1 oz cup 2-3 times with a thumbtack to allow for air flow.
5. Place a lid on your cup.
6. Place your cup in either the "warm" or the "cool" box environment based on your teachers instructions.
7. Check the containers daily to see if any of the larva have hatched. You should see them hatching after 3 days.
8. When a larva is ready to be measured take the cup out from the box and using a soft brush, transfer the larva from the cup to a balance to measure the mass and record the mass. After a larva has reached 300mg in mass, you can use the soft forceps to move them.
9. Measure the length by placing one end of the *Manduca* at the start of the ruler, then record in centimeters to the nearest millimeter how long the *Manduca* is. Record the length. As the *Manduca* grows, you may find that you need to use your fingers to

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gently lay the *Manduca* in a straight line along the ruler. Some students may feel more comfortable wearing gloves to handle the *Manduca* at this stage.

10. Before returning the larva to its cup, check its cup. If the cup looks dirty, use a paper towel and water to remove all dirty material and old food from the container. Dry the inside of the container with a paper towel, and scoop in the appropriate amount of food for that size of the cup. Place the insect back into the container with soft forceps, place the lid back onto the container, and place the container back into its appropriate box.

11. Repeat steps 8-10 every day up through pupation.

12. When the *Manduca* is ready to pupate (when it stops eating and begins "wandering" around its cup looking for a place to pupate), empty the food out of its 20 oz cup, and put 2-3 cm deep of pine shavings (hamster bedding), and a stick tilted on its side. Place the lid back on the container and place the cup back in the appropriate temperature.

13. When a moth emerges, leave it in the closed container, and place the container in a freezer over night to euthanize it, then place the moth on the balance the next day to measure its final mass. This is done to minimize the risks associated with releasing this live species into an environment that it may not be native to, and to assist with ease of the final measurements.

14. When a Manduca has outgrown its 1 oz container, it is ready to be transferred to a 20 oz cup. Label the cup with a permanent marker so that it matches the label of the original cup. Place a teaspoon of artificial diet into the larger cup, and then transfer the insect using the soft forceps. Make sure that the lid to the 20 oz cup has 4-6 holes punctured in it with a thumbtack to allow for air flow.

15. When the Manduca is ready to pupate (when it stops eating and begins "wandering" around its cup looking for a place to pupate), empty the food out of its 20 oz cup, and put 2-3 cm deep of pine shavings (hamster bedding), and a stick tilted on its side. Place the lid back on the container and place the cup back in the appropriate temperature.

16. Create a line graph for your assigned *Manduca* of length vs. days and mass vs. days using the Microsoft excel graphing link on the full virtual lab webpage or Microsoft excel on your own computer.

17. Look at your data table and graphs and find the maximal mass and longest length, and the day at which both were reached. Circle these values on your results data table.

18. Using the graphs you produced, determine how you could calculate growth rate. Write what you think on the space below:

19. Calculate the growth rate for your *Manduca*, and record in the appropriate Analysis Data Table.

20. As a class, share the maximal mass, longest length, and growth rate for each of the *Manduca* at each temperature. Record these values in the Analysis Data Tables.

21. Calculate the mean values of the entire data set for maximum length, maximal mass, and growth rate at both temperatures using the following method. Record all values in the Analysis Data Tables.

    <u>How to find the mean</u>
    1. Add up all the numbers
    2.Divide by how many numbers there are

22. Calculate the standard deviation of the entire data set for longest length, maximal mass, and growth rate at both temperatures using the following method. Record all values in the Analysis Data Tables.

23. <u>How to calculate standard deviation</u>

    1.Calculate the mean for the variable you are analyzing

    2.For each individual, determine the deviations for each of the numbers being analyzed for that variable.

        Example: longest length – mean length at that temperature = deviation

    3.Square the deviations (multiply the deviation by itself)

    4.Add up the squares of all the deviations

    5.Divide the sum of the squares by the total number of individuals minus one

        <u>Example</u>: if you had 10 individuals, minus 1 is 9, so take the sum of the squares and divide it by 9

    6.Take the square root of the answer from step # 5. This is the Standard Deviation

24. For each variable (longest length, maximal mass, and growth rate), make two graphs on your own computer or graph paper. The first graph will plot each individual value of

length, mass, and growth rate (y-axis) vs. the two temperatures (x-axis). The second graph will plot mean and standard deviation (y-axis) vs. the two temperatures (x-axis)

Example Graph 1: Individual values vs. condition – This is a plot of male and female student heights in one classroom.
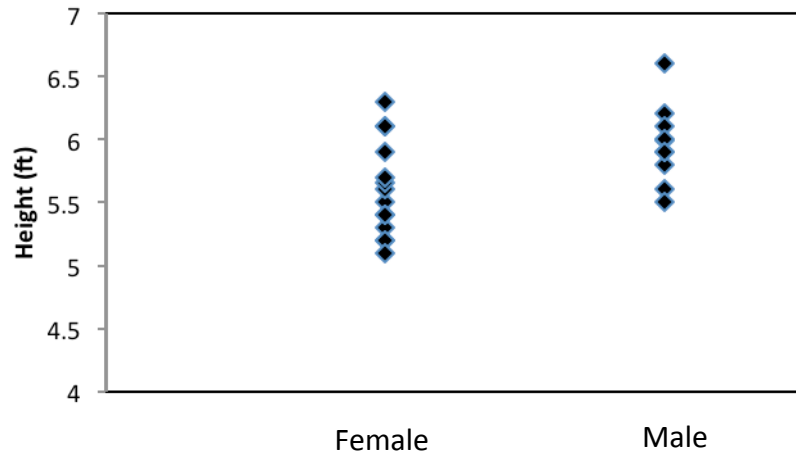
Example Graph 2: Mean and standard deviation vs. condition-This is a plot of mean height and standard deviation for male and female students in one classroom

25. Look at each of the graphs produced, and compare them. Are there any values (length, mass, growth rate, mean, standard deviation) that overlap for the two temperatures? If values from the two different temperatures do overlap, what do you think that means? If values from the two different temperatures do not overlap, what do you think that means?

Results Data Table:

Manduca grown at 20°C				Manduca grown at 30°C			
Day #	Manduca #	Mass(g)	Length(cm)	Day #	Manduca #	Mass(g)	Length(cm)

Analysis Data Tables:

Manduca #	Maximal Length (cm)	Maximal Mass (g)	Growth Rate	Deviation From Mean	Deviation squared
				Manduca Grown at 20°C	
	Mean =	Mean =	Mean =	Sum of deviation= Sum/total # of #'s-1= Standard Deviation=	

Manduca Grown at 30°C					
Manduca #	Maximal Length (cm)	Maximal Mass(g)	Growth Rate	Deviation From Mean	Deviation squared
	Mean =	Mean =	Mean =	Sum of deviation= Sum/total # of #'s-1= Standard Deviation=	

Analysis of Data:

1. Look at the growth curves from each graph. Do you think this is the best way to determine the growth rate? Why or why not? What are some other ways that you could measure growth rate?

2.Which caterpillars grew faster, the ones at the cold or warm temperature? Why do you think that happened? How sure are you of your answer, given the variation in the *Manducas* grown at each temperature?

3.Were animals larger in the cold or warm? Is your answer the same whether you use length or mass to determine size?

4.Would you change your hypothesis based on your observations? Why or why not? Are you sure-are more data needed to be sure?

5.Why do you think that cold and warm temperatures caused the *Manduca* to grow differently?

6.If temperatures are changing globally, how do you think this will affect the *Manduca* in the wild and the plants it feeds on?

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Sample Lesson Plan: The *Manduca* Growth Experiment in the Classroom

Engage (20 minutes): To get the students **engaged** with the topic of study in this lesson, show them one or more of the climate connections video clips from the link below. Choose one or more links from the Manduca growth experiment website that focus specifically on how a species on Earth is directly impacted by warming temperatures.

http://www.npr.org/news/specials/climate/video/wildchronicles.html

Following watching one or more of the video clips, have students brainstorm on their own the impacts that warming temperatures seem to have on wildlife according to the video, and the other ways that they think warming temperatures may impact wildlife. Have them share out their answers and add to their brainstormed list in groups, then share out as a class, and again have students add to their list.

Explore: Share with students that we will be **exploring** how warmer temperatures impact the size of an organism using a species that is native to Arizona, the *Manduca sexta* caterpillar, often referred to as a "hornworm" because of the horn it has at one end. It is also commonly known as the hawk moth as an adult.

You can choose to have students **explore** how global climate change can impact this native Arizona species by having them do the quick virtual lab, the full virtual lab, or the classroom experiment where they grow their own *Manduca* under cool and warm temperatures.

- The quick virtual lab exploration can be completed in one class period and could be done in pairs or groups of four depending on computer availability. Students should collect data for all days for each of the *Manduca* at the two different temperatures.

- The full virtual lab exploration can be completed in two class periods and could be done in pairs or groups of four depending on computer availability.   You could have each pair or group of students record the data for one *Manduca* from each temperature, then share their data to complete the analysis.

- The classroom experiment will take approximately 15 minutes each day for up to 36 days, and 1 full class period the final day to analyze the data. Once all of the data is collected, students will need to share out the data from their *Manduca* to the rest of the class, so that they can complete the analysis.

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Explain (20-30 minutes): Once students have collected their data either from the virtual labs or from the classroom experiment, and done a graphical and statistical analysis of the data (full virtual lab and classroom experiment only), they will attempt to **explain** what their results mean by completing the analysis questions under the analysis of data section on each of the student handouts.

It would be appropriate to give students access to the articles and websites included in the background information of this resource packet to assist them in their interpretation of the data so that they can explain what it means using scientific reasoning. Students should work in pairs or groups of four to answer the analysis questions, attempting to interpret their data using scientific reasoning that is presented in the background information.

Evaluate (1 class period): Once student pairs or groups have completed their explanations of the analysis questions, they should **evaluate** their explanations and the explanations of others. This can be done using whiteboards and a gallery walk to exchange their ideas.

- Have each pair or group pick one of the analysis questions that they answered to share with the class on their whiteboard. Encourage a diversity of choices within the questions chosen for sharing by monitoring which ones students have chosen to share, making sure that each question is shared by at least one group.

- On student whiteboards, encourage students to include as many labeled visuals in their explanations as possible (for example graphs, pictures of organisms) to assist in the interpretation of their explanation. Give students approximately 15 minutes to complete their boards.

- Following this time, ask students to set up their whiteboard on its own, leaving one whiteboard marker with a color that has not been used on any board (I usually use purple) next to each board which classmates can use to write a question for clarification on the board, or give some sort of constructive feedback on the board.

- Give students at least 15-20 minutes to then look at each of the boards in a "gallery walk" format and give feedback on the boards. Encourage students to add ideas to their own answers at this time if they feel they have a change in their ideas based on what they see. As a teacher, you may also want to give feedback on the boards if you find students are not picking up on an incorrect idea on a board, or not asking a question on a board where it seems necessary.

- Following the end of the "gallery walk" time period, take each of the boards that have questions and feedback that needs to be addressed and have that student pair/group address the question or feedback on the board as needed. This will spark classroom discussion that you will need to help facilitate with this group in order to answer questions where appropriate and to address student misconceptions that may be present in their explanations. The time it will take for this discussion will vary based on

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the number of questions that need to be addressed on each board. It will usually take no more than one class period.

- Following the end of the whiteboarding portion of the evaluation of explanations, facilitate a class discussion to complete the following statements together. This will help to ensure that all students have an appropriate understanding of the big ideas from this lab.

    The *Manduca* in the cooler environment had a _____ size over time because_____.

    The *Manduca* in the warmer environment had a _____ size over time because_____.

    The best way to determine growth rate for the *Manduca* is _____ because_____.

    We can infer that climate change can do_____ to the *Manduca* in the wild because _____ and __ _____ to the plants that the *Manduca* feed on because_____ _____.

    It is fair to say that there is a real difference in the values from two different conditions if_____.

Elaborate (2-3 class periods): Students will now be asked to **elaborate** on what they have learned from the *Manduca* growth experiment by producing a 3-5 minute video or other media campaign on how changes in global climate will likely affect an animal of their choosing, and its corresponding food source. They should choose a target audience for their video that they feel would most benefit from seeing it, and get feedback from their target audience on the impact that the video had on them.

National Science Education Standards

Unifying Content Standard: K-12
As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes: constancy, change, and measurement
Content Standard C: 5-8
As a result of their activities in grades 5-8, all students should develop understanding of: Structure and function in living systems

National Math Standards

Instructional programs from prekindergarten through grade 12 should enable all students to:
* Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them
* Develop and evaluate inferences and predictions that are based on data
* Select and use appropriate statistical methods to analyze data
* Understand measurable attributes of objects and the units, systems, and processes of measurement
* Apply appropriate techniques, tools, and formulas to determine measurements

Arizona Science Standards

5th-8th grade
SC05-S1C1-02 Formulate predictions in the realm of science based on observed cause and effect relationships
SC06-S1C1-02 Formulate questions based on obserbvations that led to the development of a hypothesis
SC05-S1C2-04 Measure using appropriate tools (e.g., ruler, scale, balance) and units of measure
SC05-S1C2-05 Record data in an organized and appropriate format (e.g., t-chart, table, list, written log).
SC05-S1C3-01 Analyze data obtained in a scientific investigation to identify trends and form conclusions
SC05-S1C4-02 Choose an appropriate graphic representation for collected data.
SC06-S1C4-01 Display Data collected from a controlled investigation (See M06-S2C1-02)

High school
SCHS-S1C1-02 Develop questions from observations that transition into testable hypotheses
SCHS-S1C2-05 Record observations, notes, sketches, questions, and ideas using tools such as journals, charts,
graphs and computers
SCHS-S1C3-06 Use descriptive statistics to analyze data, including: mean, frequency, range
SCHS-S1C3-07 Propose further investigations based on the findings of a conducted investigation
SCHS-S1C4-02 Produce graphs that communicate data

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SCHS-S4C3-02 Describe how organisms are influenced by a particular combination of biotic (living) and abiotic
(nonliving) factors in the environment

Arizona Math Standards

5th-8th grade

M05-S2C1-01 Formulate questions to collect data in a contextual situation

M05-S2C1-02 Construct a double-bar graph, line plot, frequency table or three-set Venn diagram with appropriate labels and title from organized data

M05-S2C1-05 Identify the mode(s) and mean (average) of given data

M05-S2C1-07 Compare two sets of data related to the same investigation

M07-S2C1-06 Find the mean, median (odd number of data points), mode, range and extreme values of a given
numerical data set

M07-S2C1-07 Identify a trend (variable increasing, decreasing, remaining constant) from displayed data

M08-S2C1-03 Compare trends in data related to the same investigation

M08-S2C1-08 Formulate questions to collect data in a contextual situation

High School

MHS-S2C1-02 Organize collected data into an appropriate graphical representation

MHS-S2C1-03 Display data as lists, table, matrices, and plots

MHS-S2C1-04 Construct equivalent displays of the same data

MHS-S2C1-10 Apply the concepts of mean, median, mode and quartiles to summarize data sets.

Background Information:

Manduca sexta

By Karla Moeller

What's a *Manduca*?

"Giant baby is bigger than its parents!" may make a great cover story for a magazine that publishes fake news, but in the world of moths and butterflies, it isn't unusual for the juvenile caterpillar to weigh more than the adult moth or butterfly.

One such insect is *Manduca sexta*, also known as the tobacco hornworm or hawkmoth. In this species, juveniles weigh almost five times as much as the adults. It has four main life stages: the egg, the juvenile or larva, the pupa, and the adult. Between these four life stages, the hornworm makes some astounding changes in size and form.

From tiny beginnings

Hornworm eggs start out at a tiny 1 millimeter in length—about the size of a pen tip. The eggs take a couple of days to hatch into larvae, and then the magic begins. Over a short three weeks, a hornworm will grow from about 0.01 grams to 12 grams. That is more than a 1000-fold increase in mass, about the same as if a housecat grew to the size of an elephant! Hornworms grow more than 1000 times larger in mass, the same as if a housecat grew to the size of an elephant!

Room to grow

During this period of speedy growth, the tobacco hornworm will shed its waxy skin, or cuticle, four times. This process is called molting and allows the larva to continue growing. Without molting, the cuticle would be too small, and the larva wouldn't be able to grow—this would be like wearing shoes too small for you that stunt the growth of your feet.

Ready for change

The growth period between molts is called an instar. The larval stage consists of five instars (four molts). During the final instar, the larva prepares for metamorphosis, the process by which the tobacco hornworm caterpillar is transformed into an adult hawkmoth. Once the caterpillar reaches a large enough mass called the critical weight, the process that will trigger metamorphosis begins.

Metamorphosis

First, the caterpillar goes into a "wandering stage", where it stops eating and searches for a site to transform or pupate. Pupation is the process of forming a hard brown shell, similar to a cocoon. This shell protects the tissues inside the pupa that are involved in the transformation from a caterpillar to a moth. During this process, the pupa will not be able to move. To stay safe from predators that might eat them, caterpillars will often wander into a hole in the ground to pupate.


Hornworm metamorphosis takes approximately three weeks, after which the moth emerges. During pupation, the 12 gram caterpillar is transformed into a 2 or 3 gram adult moth. The newly hatched adults mate during their nocturnal activity and the females deposit their eggs on the underside of tobacco plants. Then the cycle begins all over again.

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The role of temperature

For insects such as the hornworm, temperature has a large effect on growth, be it through changing the rate of growth or the time over which an animal grows, including the timing of metamorphosis. This means that a world that is warming or cooling could mean a lot of changes for temperature-dependent animals like insects.

Scientists are currently trying to learn about how the changes in climate that are occurring may affect animal development and survival. This is especially important for insects like the hornworm.
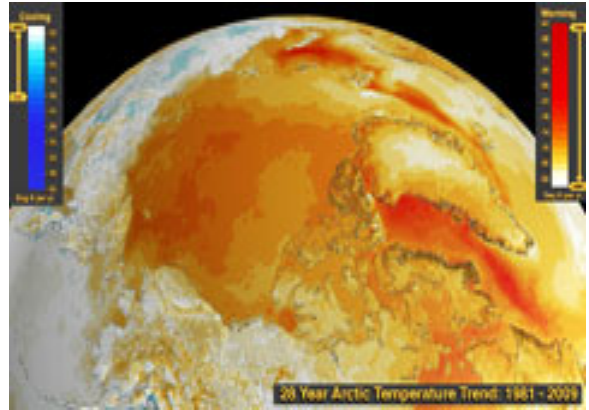
Caterpillar models

In a world filled with small caterpillars, having such a large body that is affected by temperature makes hornworms useful for scientific research. All of their tissues are larger and easier to see or work with, and they are easy to raise and handle in a laboratory setting. Most importantly, hornworms can help us learn about the effects of temperature and climate change on animal development and the timing of life cycles.

All of these characteristics have made the hornworm a species that is very useful for learning about other insects. This has made them what we call a "model organism." This doesn't mean that they pose for pretty pictures (although their bright green color does make for great photos), but it means that hornworms are an insect that we can easily use to learn more about insects and climate change in general. Seems like a pretty big job for such a big baby.

Animal Growth

Many people say "you are what you eat." There is some truth to this statement. The food that animals eat can be transformed into usable energy for cells or can be used to build new cells, which form tissues like skin and muscle.

How exactly are foods transformed into tissues during growth? The process of growth involves eating food, breaking down food through digestion, absorbing nutrients from food, and building tissue.

Step 1: Eating

To start this process of growth organisms need to eat. Insects like the *Manduca* must eat a lot in order to multiply in size by 1000 times. Many animals spend the majority of their day eating food.

Step 2: Digestion

While some animals eat their food whole, most animals chew their food to break it down into smaller pieces, this is known as mechanical digestion. These pieces aren't small enough to fit into cells, so the next step is to chemically digest the molecules in food into even smaller pieces using digestive enzymes and stomach acid. There are specific enzymes that break down the molecules found in food, which include: lipids, carbohydrates, proteins, and nucleic acids.
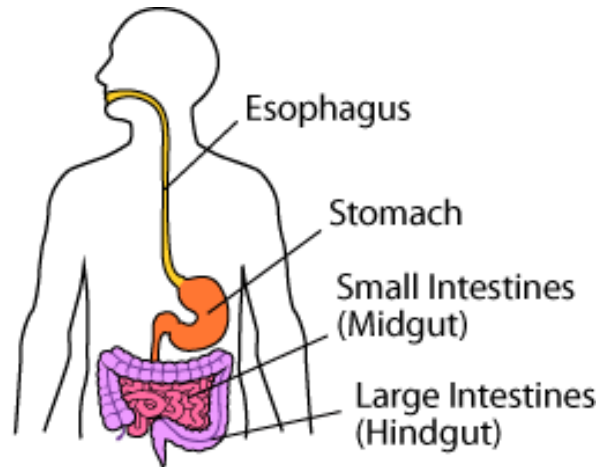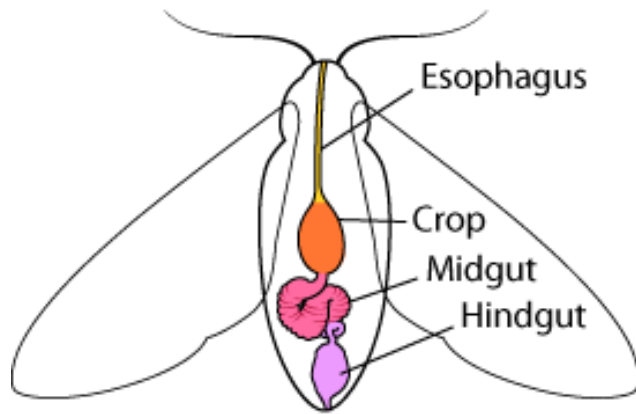
Outer Muscle Layer

Middle Muscle Layer

Inner Muscle Layer
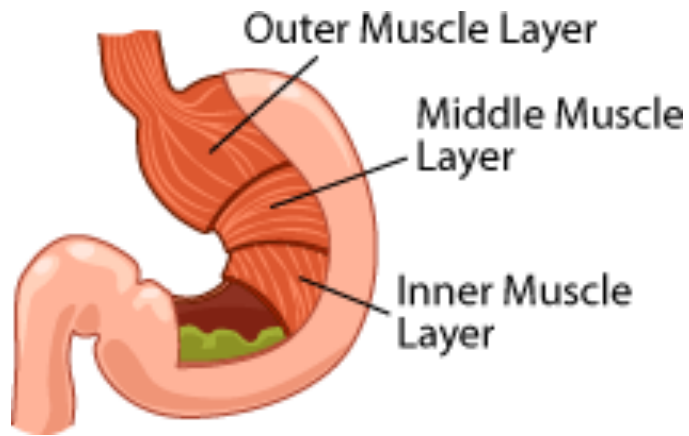
Step 3: Absorbtion and Building Tissue

Once the lipids, carbohydrates, proteins, and nucleic acids are digested, they can be transformed into usable energy for tissues, or make up the tissues themselves. For example, the proteins obtained from food are broken down into amino acids, which can be used to construct proteins found in the cells composing

Esophagus

Crop

Midgut

Hindgut

Esophagus

Stomach

Small Intestines (Midgut)

Large Intestines (Hindgut)

Temperature Transformations

Cold mornings seem to make everything slower, from getting out of bed, to tying your shoes. This is true when we look outside as well. Many animals are not active when it is cold outside, and if you are lucky enough to find a lizard or insect under a rock when it is cold outside, often times they can only move very slowly.
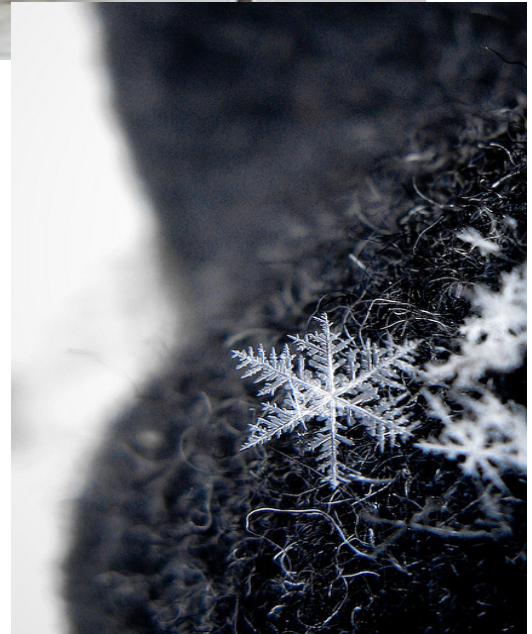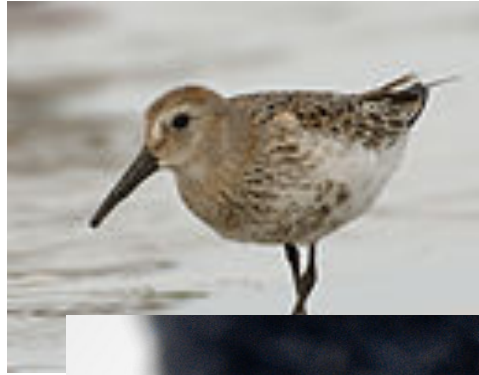

When we look at our bodies on a miniature scale, down into the reactions that occur in our cells, we find that cold temperatures are linked to slower movement. Temperature is a measure of how fast molecules are moving, and slower (colder) molecules make for slower reactions.

Humans are endotherms (commonly called "warm-blooded"), which means they create their own body heat, so in most cases, you can't blame your laziness on the cold. But for ectotherms ("cold-blooded") that don't create their own body heat, the temperature of the surroundings can affect their activity. So when a lizard is moving slowly in the cold, it is due to its muscle cells being unable to work faster. Reptiles, such as this lizard, are "cold-blooded" and cannot create their own body heat.

Movement is not the only body function that can change with the temperature. Digestion is another good example.

Lizards will move back and forth between the sun and shade to keep their bodies around a certain temperature. For most lizards, this temperature is best for digestion, or the processing of food. If they get too cold, they cannot digest food as well, and cannot get as much energy and nutrients out of their meal.

Growth is also affected by temperature in some organisms. Tissues in the bodies of these organisms may grow faster or slower if the organism is held under different temperatures. How do you think temperature affects growth? Will an animal grow faster or slower under warmer temperatures?

To answer this question, let's see what *Manduca* has to teach us about growth under different temperatures.

Manduca **growth guide** http://askabiologist.asu.edu/experiments/manduca

Sizing Up Growth

You may have heard that your adult body size depends on a few different things, such as the amount and quality of the food you eat, or what size your parents are. But what if temperature could affect how large an animal grows? What if, by being warmer or colder while growing, we could maximize growth and create larger adults? While we cannot produce hulking humans using temperature, we can produce larger or smaller insects.

However, temperature also affects growth by changing the length of the growing period. If we think about an animal that grows at the same rate, or adds the same amount of tissue to its body every day, then by increasing the number of days it can grow, it will end up larger. On the other hand, if we decrease the days of growth, it will end up smaller.

But how do lower or higher temperatures change the length of time that some organisms will grow, thereby changing how big they end up? Maybe *Manduca* can teach us a thing or two about how temperature affects the length of the growing period.

Useful Links

For additional links to articles addressing growth and temperature, as well as global climate change, visit http://askabiologist.asu.edu/manduca/links.