Non-genetic Inheritance in Oysters

Teacher Guide

Activity Overview

Calcification is a process that some marine organisms do to form their hard protective shell. Organisms take calcium (Ca^{2+}) and carbonate ions (CO_3^{2-}) from the seawater to then form calcium carbonate ($CaCO_3$), which is what the hard shell is made of. Animals have different rates at which they are able to calcify, which depends on two factors: genetics and environment. This activity will discuss both factors, but will dive deeper into the environmental component and explore current research that scientists are doing at the Northeastern University Marine Science Center. This activity requires minimal preparation and allows students to explore the topic through a comprehensive worksheet.

Learning Level

High School (9th - 12th)

Duration

Class time: 30 - 45 minutes
Teacher preparation: 5 - 10 minutes

Next Generation Science Standards

HS-LS3-1 Heredity: Inheritance and Variation of Traits
Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.

Table of Contents

Focus Question

Does the growth rate of oyster larvae depend on the environment of their parents?

Objectives

Students will be able to:
- Describe the factors that influence how molluscs make their shells
- Describe factors that influence the inheritance and expression of species traits
- Interpret graphs with multiple factors plotted

Attributions

This activity, created by Dr. Katie Lotterhos, is based on research conducted in the Lotterhos Lab at the Northeastern University Marine Science Center. The development of this activity was funded by NSF-OCE 1635423 and NSF-DEB 1655701 to Dr. Katie Lotterhos.

Background

This information is also on the student worksheet, shown at the end of the packet

Molluscs are soft-bodied invertebrates that typically make their own shell, a process known as **calcification**. In this calcification process, molluscs uptake calcium and carbonate ions that are available in the seawater. The effectiveness and efficiency of this process depends on the chemistry of the seawater. When there are many ions available, calcification requires less energy for the organism. However, the opposite is true - when there are fewer ions in the water, the organism needs to work harder to collect them. This availability of ions is called **saturation state.**

Linked here is a video by the Alliance for Climate Education about calcification and ocean acidification that may help students to understand the topic.

The ability for organisms to calcify has a **genetic basis**. Traits that have genetic basis have slight variations in their DNA sequence that cause differences among these traits. Some traits with a genetic basis, such as human height, are influenced by many **genes**. This is called a **polygenic trait**. For polygenic traits, the trait that the offspring will have, on average, can be predicted by the average of the parents.

In the case of oysters, the calcification rate (e.g., growth rate) is a polygenic trait. The rate varies among individuals, depending on their genetic makeup. Genetic makeup varies among individual oysters because they reproduce by **broadcast spawning**, a form of sexual reproduction used by many aquatic invertebrate animals. Billions of gametes (sperm and egg) are spewed into the surrounding environment of the ocean. These gametes combine to form **larvae**.

The environment of organisms, in addition to genetics, plays a role in influencing traits. For example, in humans, studies have shown that women who smoke during pregnancy induce lasting effects to herself, her child, and her grandchild. These children and grandchildren are more likely to be obsese than those of women who did not smoke during pregnancy.

These effects are not caused by changes to the DNA sequence itself, but by changes in the molecules surrounding DNA. For example, proteins called histones play a key role in the packing of DNA into chromosomes. However, they also are important for regulating genes. When there are changes to the way DNA is wrapped around histones, it causes **non-genetic inheritance**. The same is true for molecules called methyl groups that bind to DNA. Changes to the way these molecules bind to DNA causes non-genetic inheritance. In principle, non-genetic inheritance comprises all parent–offspring mechanisms of inheritance, except the transmission of the DNA sequence.

The degree to which the environment influences traits depends on three factors: the trait itself, the genetic basis for that trait, and the type of environment. For many species, the amount that genetics and the environment influence species traits, especially across generations, is unknown. Scientists are especially interested in the impact of environmental factors on future generations of oysters because they provide many ecosystem services, such as water filtration and habitat creation. The environment that oysters live in has been changed due to direct effects of human activities, such as fishing and farming, as well as indirect effects, such as warming and ocean acidification.

Materials

For each student:

- 'Non-genetic Inheritance in Oysters' student worksheet
- Writing utensil

Teacher Preparation

1. Educators can create a presentation on this material if helpful

Procedure

Step 1. Introduce focus question to the class (5 minutes)
Pose the focus question, *"Does the rate that oyster larvae grow depend on the environment of their parents?"*, to the class and begin the lesson with a short discussion. Have any students heard of such an instance? Do any students have hypotheses or predictions about how the parental environment will affect offspring? What makes them think this?

Step 2. Provide the context for the activity topic (5 minutes)
Once the short discussion finishes, begin introducing the topic of the activity: non-genetic inheritance in oysters. Information about this topic can be found in the 'background' section earlier in this packet.
Explain that calcification is a process that some marine organisms do to form their hard protective shell. Organisms take calcium (Ca^{2+}) and carbonate ions (CO_3^{2-}) from the seawater to then form calcium carbonate ($CaCO_3$), which is what the hard shell is made of.

To ensure understanding of this topic, show students this video by Alliance for Climate Education on calcification and ocean acidification.

Then, explain that animals have different rates at which they are able to calcify, and this depends on two factors: genetics and environment. This activity will discuss both factors, and will dive deeper into the environmental factor.

Step 3. Set up the activity (2 minutes)
Provide the student worksheet to each student.

Step 4. Conduct the activity (15-25 minutes)
Go through the information on the worksheet with students as a class. When a question on the worksheet arises, allow students to answer on their own, but then bring the class together to have a disucssion. In this discussion, ask students what they wrote down and why they answered they way they did. Ensure that all students have an understanding of the topic before moving on.

The student worksheet plus answers to the questions are at the end of this packet.

Step 5. Discuss main takeaways and evaluate understanding of the topic (5-10 minutes)
To evaluate the understanding of the topic, ask students to describe how non-genetic inheritance works. How is it possible for traits to be passed down if not through DNA?

As a summarizing statement, return back to the focus question at the beginning, *"Does the rate that oyster larvae grow depend on the environment of their parents?"* Discuss the findings of the scientists at the Marine Science Center on this topic. They found that there is an effect of the environment on the growth of oysters. This effect was greater at low saturation states than at high saturation states. Research is still being conducted on this topic and is important for understanding species responses for global change.

Vocabulary

broadcast spawning: a form of sexual reproduction used by many aquatic invertebrates where both eggs and sperm are released into the water column and fertilization occurs externally
calcification: the formation of calcium carbonate by marine organisms
genes: a unit of heredity that is transferred from parent to offspring and determines some characteristic of the offspring
genetic basis: due to genes
ion: an atom or molecule that carries an electric charge
larva: the distinct juvenile form many animals undergo before metamorphosis into adults
mollusc: an invertebrate with a soft unsegmented body that typically has an external calcareous shell
non-genetic inheritance: the transmission of parental factors, other than DNA sequences, to offspring that then affect their phenotype
polygenic trait: a trait whose phenotype is influenced by more than one gene
saturation state: the number of ions available for calcification

References

Day, J. J. and J. D. Sweatt. 2010. DNA methylation and memory formation. *Nature Neuroscience* **13**: 1319–1323.

McNally, E. M., A. Downey-Wall, F. Titmuss, C. Cortina, K. E. Lotterhos, and J. B. Ries. 2021. Parental environment affects larvae biomineralization in the response of the eastern oyster, *Cassostrea virginica*, to ocean acidification. In preparation.

Supplemental Material

Alliance for Climate Education. 2016. ACE Science Short: Ocean Acidification.
https://www.youtube.com/watch?v=6SMWGV-DBnk&ab_channel=AllianceforClimateEducation

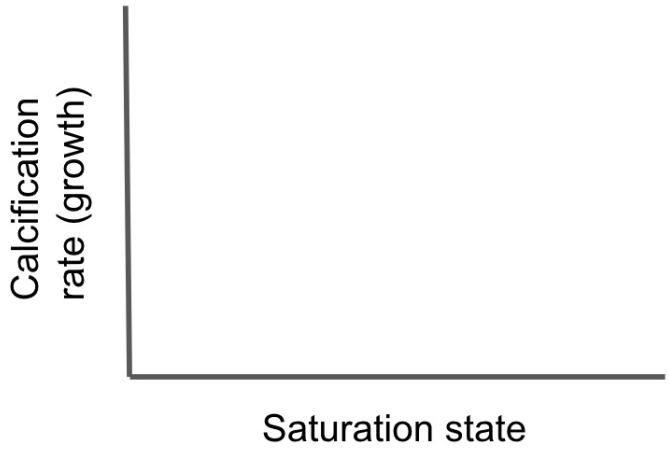
Copyright

Student Worksheet Solutions

Instructor's Note: These worksheet solutions contain the information that is on the student packet as well as additional information that may be helpful to the instructor, such as instructor's notes and problem solutions. This additional instructor information can be found in the grey boxes, while the information students have is on the normal white background.

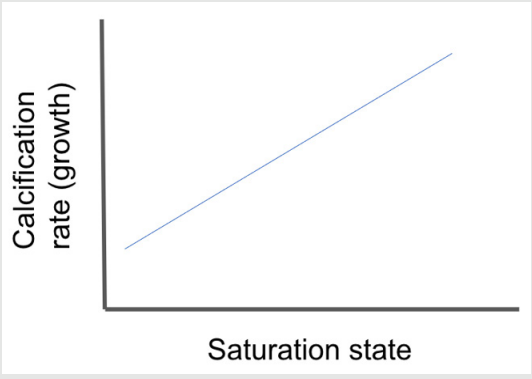
Molluscs are soft-bodied invertebrates that typically make their own shell, a process known as **calcification**. In this calcification process, molluscs uptake calcium and carbonate ions that are available in the seawater. The effectiveness and efficiency of this process depends on the chemistry of the seawater. When there are many ions available, calcification requires less energy for the organism. However, the opposite is true - when there are fewer ions in the water, the organism needs to work harder to collect them. This availability of ions is called **saturation state**.

1. Draw a picture of the relationship between calcification (y-axis) and saturation state (x-axis).



Instructor's Note: Pause the lesson and allow students to answer the question individually. Once all students have answered, discuss the answer as a class.

Solution: A direct relationship



The ability for organisms to calcify has a **genetic basis**. Traits that have genetic basis have slight variations in their DNA sequence that cause differences among these traits. Some traits with a genetic basis, such as human height, are influenced by many **genes**. This is called a **polygenic trait**. For polygenic traits, the trait that the offspring will have, on average, can be predicted by the average of the parents.

Instructor's Note: Pause the lesson again and let students answer the two questions below. Then have a discussion.

2. What are some traits, other than height, that have a genetic basis in humans?

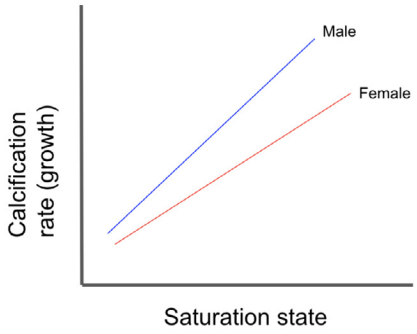
Solutions: height, skin color, eye color, hair color, ability to roll tongue, ability to taste certain sour flavors, earlobe attachment, etc.

3. What is the predicted height of an average offspring from a mother who is 5'7" and a father who is 5' 9"? Show your work below.

Solution: (5'7" + 5'9")/2 = 5'8"

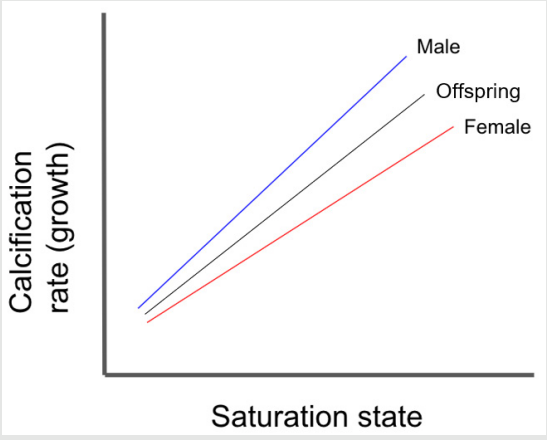
In the case of oysters, the calcification rate (e.g., growth rate) is a polygenic trait. The rate varies among individuals, depending on their genetic makeup. Genetic makeup varies among individual oysters in part because they reproduce by **broadcast spawning**, a form of sexual reproduction used by many aquatic invertebrate animals. Billions of gametes (sperm and egg) are spewed into the surrounding environment of the ocean. These gametes combine to form **larvae**.

4. Draw a line on the graph below that represents the predicted calcification rate for the average offspring of the male and female oyster.



Instructor's Note: Pause the lesson and let students answer the question. Then have a discussion.

Solution: The offspring's calcification rate would be right inbetween the rate of the male and the female oysters.



The environment of organisms, in addition to genetics, plays a role in influencing traits. For example, in humans, studies have shown that a women who smokes during pregnancy induces lasting effects to herself, her child, and her grandchild. These children and grandchildren are more likely to be obsese than those of women who did not smoke during pregnancy.

These effects are not caused by changes to the DNA sequence itself, but by changes in the molecules surrounding DNA (see image below). For example, proteins called histones play a key role in the packing of DNA into chromosomes. However, they also are important for regulating genes. When there are changes to the way DNA is wrapped around histones, it causes **non-genetic inheritance**. The same is true for molecules called methyl groups that bind to DNA. Changes to the way these molecules bind to DNA causes non-genetic inheritance. In principle, non-genetic inheritance comprises all parent–offspring mechanisms of inheritance, except the transmission of the DNA sequence.

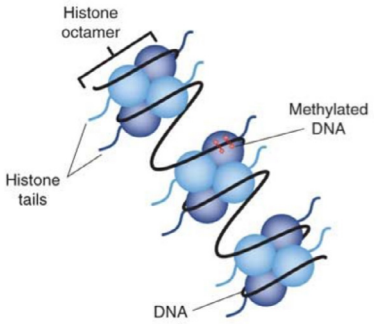


Image by J. J. Day and J. D. Sweatt

5. What are two other environmental factors that may cause non-genetic inheritance in humans?

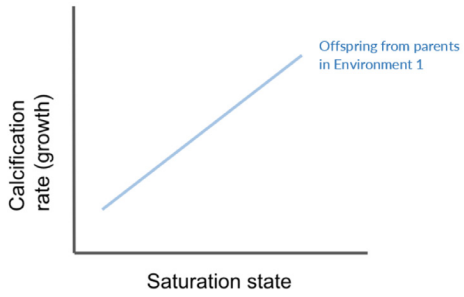
Instructor's Note: Pause the lesson and allow students to answer the question individually. Then discuss.

Solutions: smoking, drug use, alcohol, famine

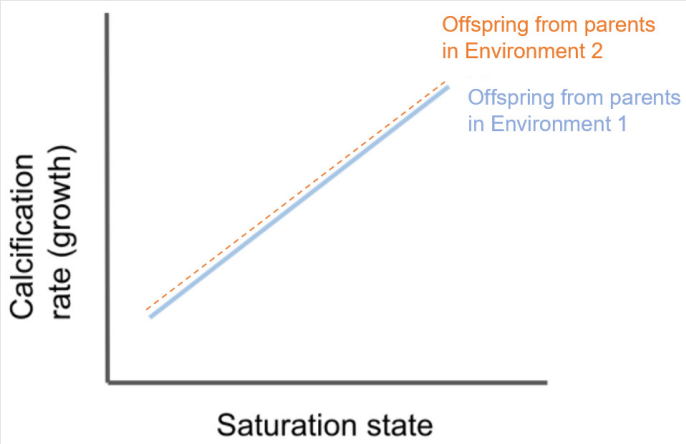
The degree to which the environment influences traits depends on three factors: the trait itself, the genetic basis for that trait, and the type of environment. For many species, the amount that genetics and the environment influence species traits, especially across generations, is unknown. Scientists are especially interested in the impact of environmental factors on future generations of oysters because they provide many ecosystem services, such as water filtration and habitat creation. The environment that oysters live in has been changed due to direct effects of human activities, such as fishing and farming, as well as indirect effects, such as warming and ocean acidification.

To study this specific example, scientists conduct an experiment in which they expose parents to different environments, and raise their larvae in high and low saturation states. The results of this experiment can be sorted into two broad categories: the environment of the parents **did not influence** the calcification rate of the offspring vs. the environment of the parents **did influence** the calcification rate of the offspring. The questions below explore what the data may look like for each situation.

6. If the environment of the parents **did not influence** the calcification rate of the offspring, how would the calcification rate differ for offspring whose parents were raised in Environment 1 vs. Environment 2? The pattern for offspring from parents raised in Environment 1 is already drawn on the graph below. Draw the calcification pattern for offspring whose parents were raised in Environment 2 on the graph below relative to data already drawn. (Hint: there is only one possible outcome)

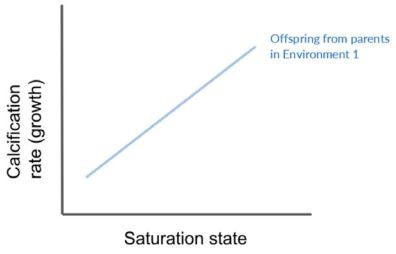


Instructor's Note: Allow students to answer on their own, but then discuss with the whole class. It may be beneficial to draw this out on the board.

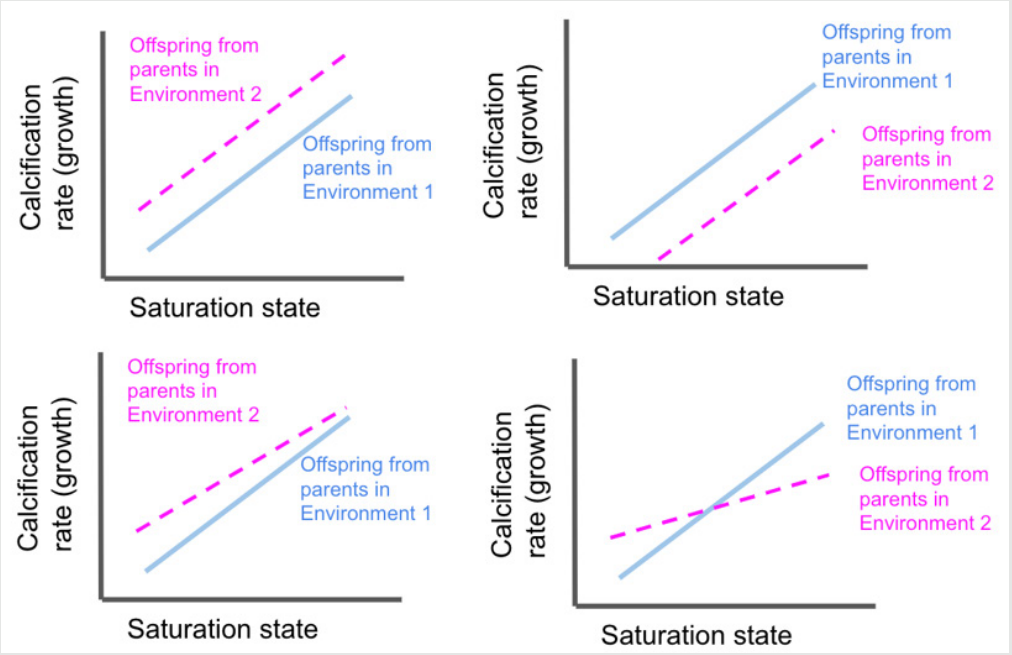


Solution: The rate of calcification for offspring from parents raised in Environment 1 vs. Environment 2 would be *the same* if there is no environmental influence.

7. If the environment of the parents **did influence** the calcification rate of the offspring, how would the calcification rate differ for offspring whose parents were raised in Environment 1 vs. Environment 2? Draw the calcification pattern for offspring whose parents were raised in Environment 2 on the graph below relative to data already drawn. (Hint: There are multiple possible outcomes)

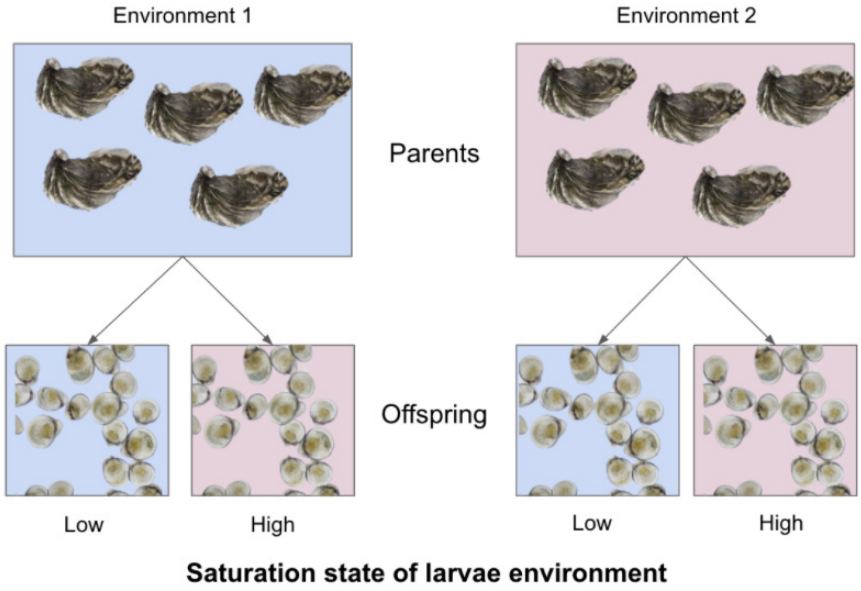


Instructor's Note: Let students answer, and then discuss.

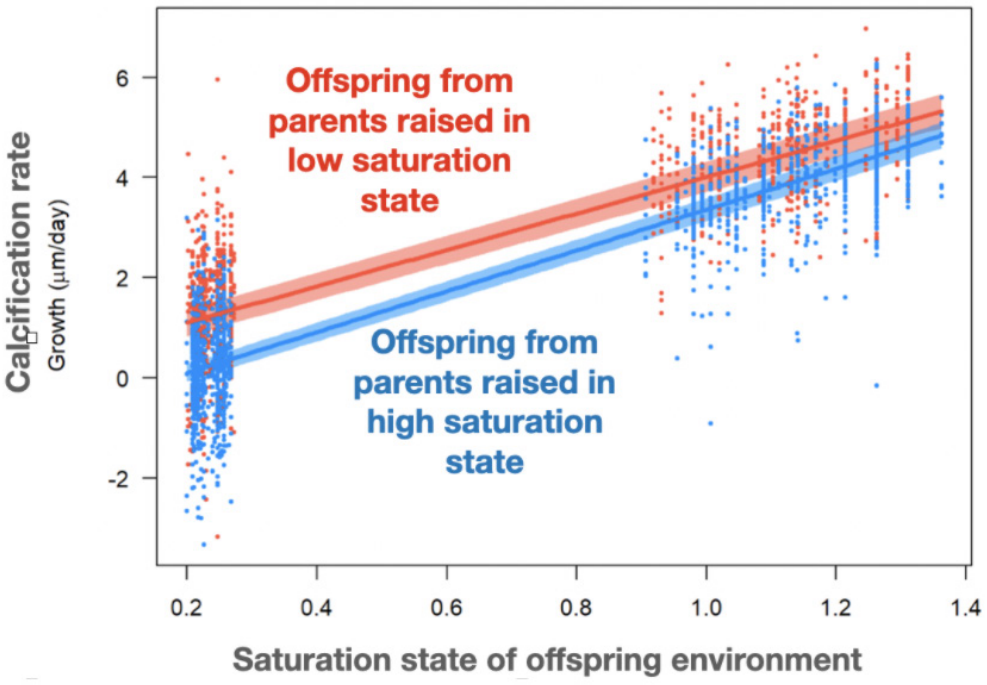


Solution: The rate of calcification for offspring from parents raised in Environment 1 vs. Environment 2 would *be different* if there was environmental influence. There are many possible answers, and they are correct as long as the two rates are different.

In 2018, the Lotterhos Lab at Northeastern University performed the type of experiment mentioned above. They raised parents at low and high saturation states, then raised larvae at low and high saturation states, shown again in the figure below.



The lab analyzed the data and created the graph below. In this graph, each dot represents an individual larvae whose growth was measured, and color indicates the environment of their parents. The lines show the average relationship for larvae whose parents experienced that environment, while the shading around the lines shows the uncertainty in the slope of the lines, given the variation in the data.



Based on the saturation state vs. calcification rate graph on the previous page, answer the following questions.

Instructor's Note: Decide whether to let students answer all the questions and then discuss as a class, or discuss each question one by one.

8. Is there evidence for non-genetic inheritance in oysters? Why?

Solution: Yes, because the parental environment influenced the growth rate of oysters.

9. Overall, how does saturation state influence larval growth?

Solution: Larval growth increases with saturation state.

Instructor's note: This question is asking about the overall slope of the lines, regardless of parental environment. In statistics, we call this a "main effect" of saturation state.

10. Overall, how does the parent environment influence larval growth?

Solution: Larvae from parents who were raised in a low saturation state had overall higher growth than larvae from parents who were raised in a higher saturation state environment.
Instructor's note: This question is asking about the overall difference between the lines, regardless of the value on the x-axis. In statistics, we call this a "main effect" of the parental environment.

11. Does the parent environment influence larvae growth consistently across saturation states? Describe how parental environment influences larvae growth at high and low saturation states.

Solution: No. The difference between larval growth is larger at low saturation states than at high saturation states.

Instructor's note: This question is asking about whether the lines are parallel. When they are not parallel, in statistics we call this an "interaction" between parental environment and saturation state.

12. What did you learn in this lesson?

Solution: Anything that is relevant to the lesson

Name: _____ **Date:** _____

Non-genetic Inheritance in Oysters

Activity Worksheet

Focus Question

Does the growth rate of oyster larvae depend on the environment of their parents?

Objectives

Students will be able to:

- Describe the factors that influence how molluscs make their shells
- Describe factors that influence the inheritance and expression of species traits
- Interpret graphs with multiple factors plotted

Activity

Molluscs are soft-bodied invertebrates that typically make their own shell, a process known as **calcification**. In this calcification process, molluscs uptake calcium and carbonate ions that are available in the seawater. The effectiveness and efficiency of this process depends on the chemistry of the seawater. When there are many ions available, calcification requires less energy for the organism. However, the opposite is true - when there are fewer ions in the water, the organism needs to work harder to collect them. This availability of ions is called **saturation state**.

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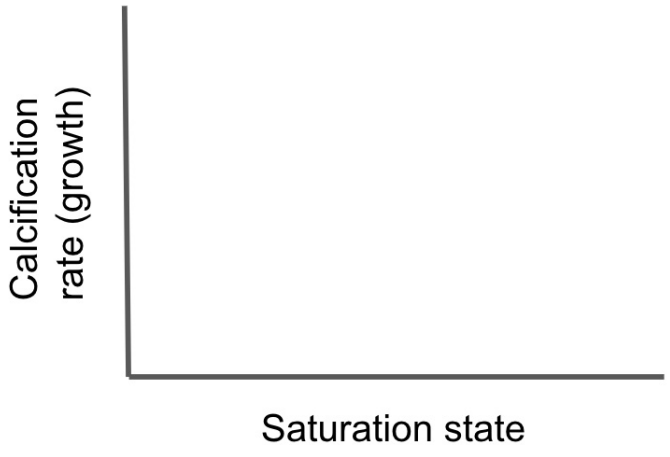

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2. What are some traits, other than height, that have a genetic basis in humans?

_____

_____

3. What is the predicted height of an average offspring from a mother who is 5'7" and a father who is 5' 9"? Show your work below.

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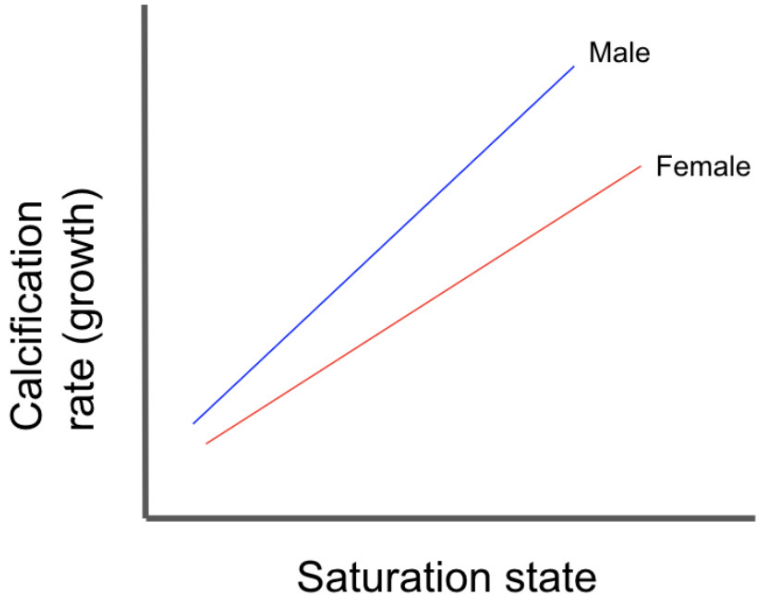

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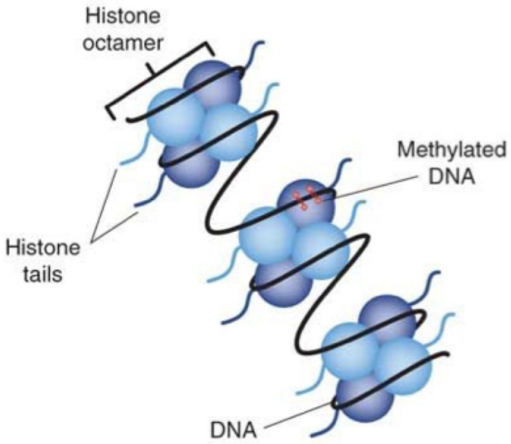

Image by J. J. Day and J. D. Sweatt

5. What are two other environmental factors that may cause non-genetic inheritance in humans?

_____

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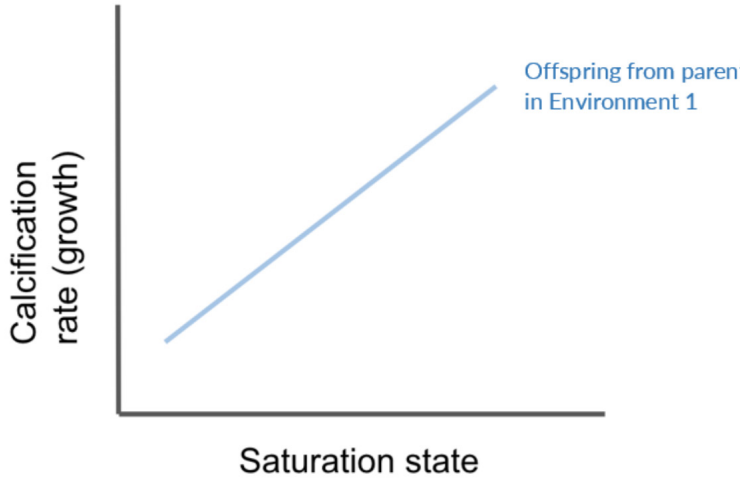
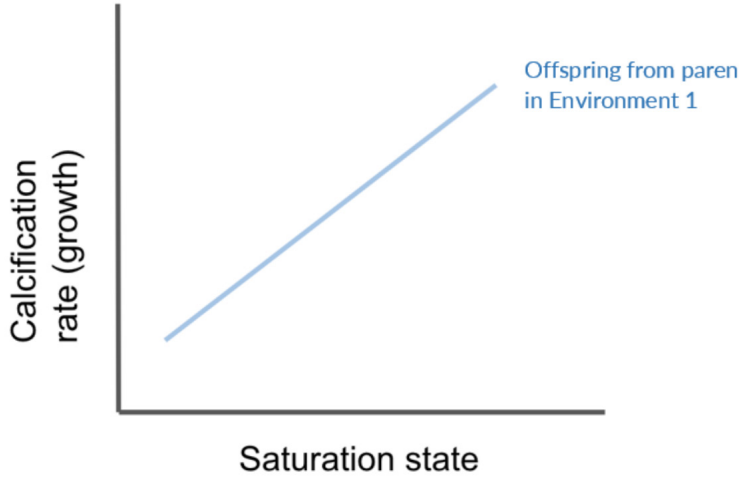
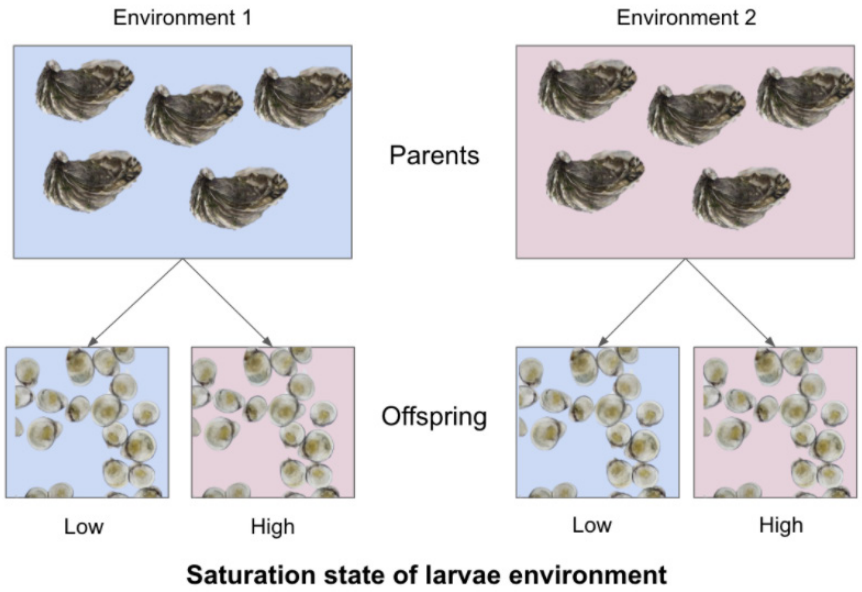


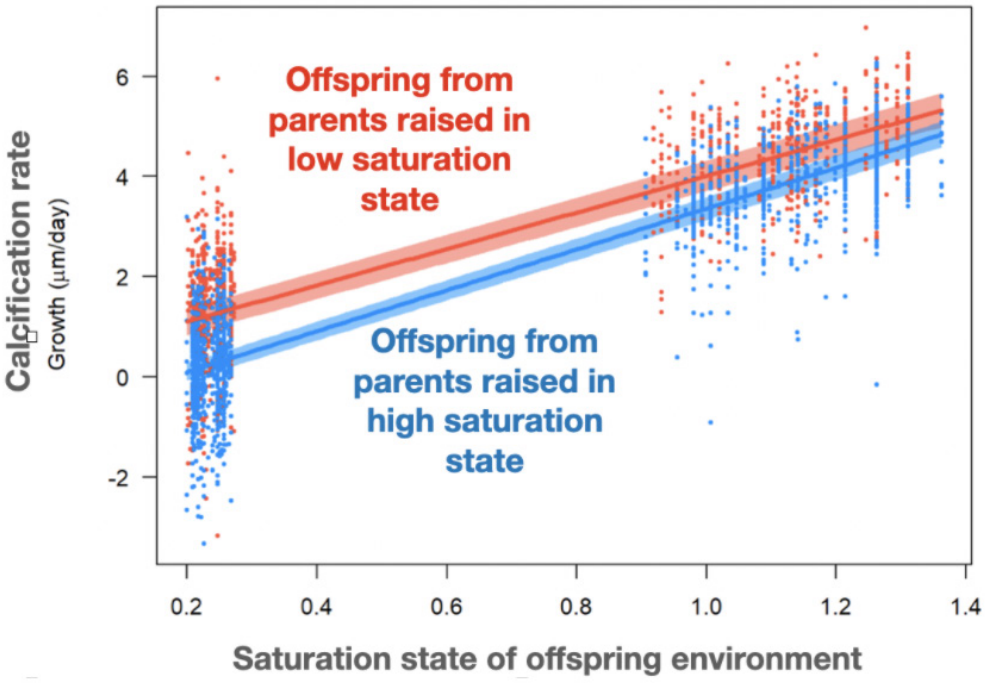
7. If the environment of the parents **did influence** the calcification rate of the offspring, how would the calcification rate differ for offspring whose parents were raised in Environment 1 vs. Environment 2? Draw the calcification pattern for offspring whose parents were raised in Environment 2 on the graph below relative to data already drawn. (Hint: There are multiple possible outcomes)



In 2018, the Lotterhos Lab at Northeastern University performed the type of experiment mentioned above. They raised parents at low and high saturation states, then raised larvae at low and high saturation states, shown again in the figure below.



The lab analyzed the data and created the graph below. In this graph, each dot represents an individual larvae whose growth was measured, and color indicates the environment of their parents. The lines show the average relationship for larvae whose parents experienced that environment, while the shading around the lines shows the uncertainty in the slope of the lines, given the variation in the data.



Based on the saturation state vs. calcification rate graph on the previous page, answer the following questions.

8. Is there evidence for non-genetic inheritance in oysters? Why?

9. Overall, how does saturation state influence larval growth?

10. Overall, how does the parent environment influence larval growth?

11. Does the parent environment influence larvae frowth consistently across saturation states? Describe how the parental environment influences larvae growth at high and low saturation states.

What causes the patterns in this data? The Lotterhos Lab is collaborating with the Roberts Lab at the University of Washington to study whether these effects could be caused by the parental environment altering DNA methylation. This is an active area of research and important for understanding species responses for global change.

Thank you for your participation! The scientists at Northeastern University's Marine Science Center are excited to share our cutting-edge research with you.

12. What did you learn in this lesson?

Vocabulary

broadcast spawning: a form of sexual reproduction used by many aquatic invertebrates where both eggs and sperm are released into the water column and fertilization occurs externally
calcification: the formation of calcium carbonate by marine organisms
genes: a unit of heredity that is transferred from parent to offspring and determines some characteristic of the offspring
genetic basis: due to genes
ion: an atom or molecule that carries an electric charge
larva: the distinct juvenile form many animals undergo before metamorphosis into adults
mollusc: an invertebrate with a soft unsegmented body that typically has an external calcareous shell
non-genetic inheritance: the transmission of parental factors, other than DNA sequences, to offspring that then affect their phenotype
polygenic trait: a trait whose phenotype is influenced by more than one gene
saturation state: the number of ions available for calcification

Supplemental Material

To learn more about non-genetic inheritance in humans, follow the links below.
Dutch Hunger Famine: https://tinyurl.com/DutchHungerFamine and doi.org/10.1111/1471-0528.12136
Effects of Smoking: https://harvardmagazine.com/2017/05/is-epigenetics-inherited

Attributions

This activity, created by Dr. Katie Lotterhos, is based on research conducted in the Lotterhos Lab at the Northeastern University Marine Science Center. The development of this activity was funded by NSF-OCE 1635423 and NSF-DEB 1655701 to Dr. Katie Lotterhos.

About the Scientist

Behind this activity is a scientist working on valuable research in the marine science field. **Dr. Katie Lotterhos** is an assistant professor at the Northeastern University Marine Science Center. Her research uses eco-evolutionary genomics to understand how climate has shaped biodiversity and how a now rapidly changing climate will affect biodiversity in the future. To learn more about Dr. Lotterhos' research, please follow the information below.

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