



HOW DID DINOSAURS REGULATE THEIR BODY TEMPERATURES?

OVERVIEW

This activity is designed to supplement the viewing of the short film *Great Transitions: The Origin of Birds* (<http://www.hhmi.org/biointeractive/great-transitions-origin-birds>). Students use authentic data to investigate the following question raised in the film: How did dinosaurs regulate their body temperatures? The activity uses data from a recent study (Grady et al., 2014) published in *Science* magazine, which focused on whether, metabolically, dinosaurs were more similar to reptiles or birds, or to something in between the two groups.

KEY CONCEPTS AND LEARNING OBJECTIVES

- Animals fall somewhere on the continuum from ectothermic to endothermic, depending on how they maintain and regulate their internal body temperatures.
- “Resting metabolic rate” refers to the minimal amount of energy an animal has to expend, at rest, to maintain life processes. “Growth rate” refers to how much an animal grows per unit of time. Since growth is a result of metabolic activity, resting metabolic rate and growth rate have a direct relationship—the higher the metabolic rate, the faster the growth rate tends to be.
- Ectotherms have lower resting metabolic and growth rates than do endotherms of similar size.
- Fossilized bones contain information that can be used to estimate the resting metabolic rates and growth rates of dinosaurs.

Students will be able to

- analyze, interpret, and draw conclusions from authentic data and
- participate in a collaborative discussion of the evidence with their classmates.

CURRICULUM CONNECTIONS

Curriculum	Standards
NGSS (April 2013)	HS-LS4-1, HS-LS1-7
Common Core (2010)	Math.Content.F-IF.4, F-LE.2, F-LE.3
AP Biology (2012–2013)	1.A.4, 2.A.1, 2.C.2, 2.D.2
IB Biology (2016)	2.8, 5.1, 6.6

KEY TERMS

ectotherm(ic), endotherm(ic), growth rate, homeostasis, mesotherm(ic), metabolism, resting metabolic rate, thermoregulation

TIME REQUIREMENTS

This activity is designed to be completed within one or two 50-minute class periods, including the time needed to view the film (20–25 minutes). You can minimize in-class time by assigning parts for homework.



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SUGGESTED AUDIENCE

This activity is appropriate for high school biology, but is probably better suited to AP and IB Biology courses. This activity is appropriate for introductory college biology.

PRIOR KNOWLEDGE

Students should be familiar with the basic concepts of common ancestry and the transformation and conservation of energy, especially as it relates to cellular respiration. It would be helpful if students had some familiarity with interpreting graphs that use logarithmic scales.

TEACHING TIPS

- Students should watch the film *Great Transitions: The Origin of Birds* before engaging with this activity. When student watch the film, have them pay particular attention to any mention of metabolism or “warm/cold bloodedness.”
- The reading level of the student document is fairly high so the activity could be challenging to students who are not strong readers. Some students might take longer or need extra support.
- You may want to explain to students that the terms “warm blooded” and “cold blooded” have fallen out of favor because they suggest that the blood itself is either hot or cold—and it isn’t that simple. For example, a snake basking in the sun could, at that moment, have warmer blood than a human! It’s much better to classify animals based on the source of their heat (internal/external; endothermic/ectothermic). In addition, animals can be distinguished by how stable they maintain their internal temperatures. The terms “homeothermic” (animals that maintain a somewhat constant internal temperature), “poikilothermic” (animals whose internal temperatures can vary widely), and “heterothermic” (animals that can switch on a daily or annual basis between ectothermic and endothermic strategies) are not used in the activity, but if students are familiar with them already, they can be helpful tools in talking about thermoregulation.
- If your students need some extra time to go over the basics, you may find it helpful to pass out the introduction, “Thermoregulation in Living Animals,” to each student before handing out Parts 1–4. You could then have students read the handout and ask questions as a group before starting the activity.
- The graphs are in color. If student documents are printed in black and white, you may wish to display the color graphs (Figures 2 and 3 in student document) on a large screen using a data or overhead projector. Alternatively, tell students which animals are endotherms and have students highlight those names in Figure 2. You may wish to do something similar for Figure 3.
- To help with the graph (Figure 2) in Part 1, pick a couple of data points and show how they were plotted. For example, the emerald rock cod has a mass of nearly 180 grams, so its point is located in the x-plane between the 100 line and the next line to the right, which represents 200. Its metabolic rate is 0.035, so its location in the y-plane is two lines up from the 0.01 line, which represents 0.03.
- After completing each part of the activity, conduct a brief class discussion of the answers to each question to ensure that students can follow from one part to the next.



Short Film
Great Transitions: The Origin of Birds

- In Part 3, students may have questions about the weight-independent labels of the graph's axes (see Figure 3). If necessary, explain that the growth and metabolic rate values are treated mathematically in such a way as to produce a straight line on the graph.
- In Part 3, Question 16, students are provided with the following information: "Grady and colleagues made their data available to all other scientists. One scientist reanalyzed their data using some different assumptions and came to an alternative conclusion. This scientist also carefully described the methods he used for his calculations. Grady and colleagues reviewed the work of the other scientist and replied with an argument about why they concluded their method of calculating metabolic rates was correct." The main contention of the scientist who reanalyzed the data, Dr. Michael D'Emic of Stony Brook University, is that because dinosaurs displayed seasonal growth, the growth rate estimates calculated by Dr. Grady and colleagues should be doubled. In their response, Dr. Grady and colleagues pointed out that most animals also show seasonal growth: "Thus, if we followed his recommendation and doubled the rates to reflect discontinuous growth, we would have to do it for all the groups in our analysis, leading to no change in the overall results: comparing patterns of dinosaur growth with the observed growth rate of living vertebrates clearly shows that non-avian dinosaurs were mesotherms." The calculations by Dr. D'Emic and colleagues suggest that dinosaurs were endotherms. Discuss with students that these arguments are common in the scientific literature, especially in new areas of research. As more studies are done and the research is evaluated by more scientists, a scientific consensus is often reached.

ANSWER KEY

INTRODUCTION: THERMOREGULATION IN LIVING ANIMALS

1. Look at the images of the four animals in Figure 1. Imagine that you measured the temperature inside each animal and also the temperature in the environment where the animals live. Would you expect any differences between the animals and the environment? Would the pattern be the same for all the animals? Why or why not?

The initial question serves as a pre-reading activity to help students anticipate what they are about to read. Because this question asks about students' initial ideas, be open to a range of responses. Some students may already recognize that the ectotherms in the photos will have internal temperatures similar to the environment, whereas the endotherms may have internal temperatures that differ significantly from external temperatures.

2. Write definitions for "**endothermic**" and "**ectothermic**" using your own words. List four examples of animals that would fit into each category.

The definitions in the reading are, "The body temperatures of ectothermic animals are mostly determined by the outside environment, whereas endotherms rely on heat generated inside their bodies to regulate temperature." Students should give similar answers but in their own words. For example, be open to a range of responses, as the reading has not provided a definitive grouping yet. Later the text mentions, "Amphibians, and most reptiles, fish, and invertebrates are ectotherms, whereas mammals and birds are endotherms."



3. A major scientific principle is that energy is neither created nor destroyed, but it can be transferred or transformed. Summarize some of the transformations of energy described in the last two paragraphs.

Some of the transformations of energy mentioned are chemical energy in food being converted into heat and for doing work such as moving, growing, or reproduction. Energy is also transformed when muscles contract rapidly and heat is released.

4. Make a prediction of whether you think dinosaurs were more like endotherms or ectotherms. Include the reasons for your prediction.

This question is meant to help engage students in the reading that will come in Part 2 and provide them a reason to complete the reading. Be open to a range of logical responses.

PART 1: METABOLISM AND MASS OF LIVING ANIMALS

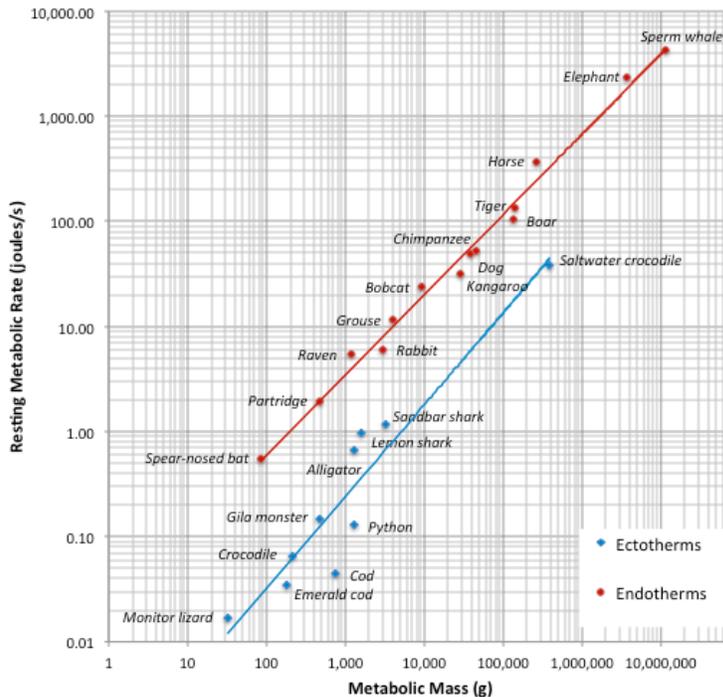


Figure 2. Metabolic Rate versus Metabolic Mass of Vertebrates. This graph appears as Figure 2 in the student handout (but without the lines of best fit). Adapted from Grady, John M., Brian J. Enquist, Eva Dettweiler-Robinson, Natalie A. Wright, and Felisa A. Smith. 2014. "Evidence for Mesothermy in Dinosaurs." Supplementary Materials. *Science*, 344, no. 6189 (2014): 1268–1272.

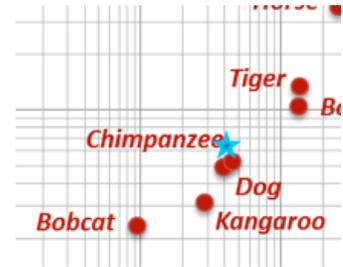
1. Look first at the general trends on the graph. How do the metabolic rates of endotherms compare with those of ectotherms?

Students should note that at any given mass, the metabolic rates of endotherms are higher than those of ectotherms and that within each set (ectotherms, endotherms) the greater the mass of the animal the greater the resting metabolic rate.

2. An average adult cheetah has a mass of 44,010 grams and a metabolic rate of 61.77 joules per second. Use these data to place the cheetah on the graph. Based on these data, would you characterize the cheetah as an endotherm or ectotherm? How do you know?



Students should plot the point slightly above those of the chimpanzee and dog, where the blue star is in the graph to the right. They should conclude that a cheetah is an endotherm because its placement on the graph is in trend with the endotherms, not the ectotherms.



3. Briefly describe data you could collect that would provide additional evidence to directly support the placement of the cheetah as an ectotherm or an endotherm.

Additional data that would support the placement of the cheetah as an endotherm would be from directly measuring the internal temperature of a cheetah in a range of external temperatures. If the internal temperature of the cheetah stayed relatively constant, the evidence would support the classification of the cheetah as an endotherm.

4. As the masses of the animals increase, how do their metabolic rates change?

For both endotherms and ectotherms, there is a trend toward increasing metabolic rate with increasing mass. The correlation in ectotherms is not as clear as it is for endotherms.

If students have a strong background in math, you may want to remind them that the graph is a log-log graph. A linear relationship on a log-log graph is indicative of a power function. Therefore, metabolic rates increase as a power function of mass.

5. Use the data in Figure 2 to make a claim about how the metabolic rates of endotherms compare with those of ectotherms for animals of similar mass. Support your claim with at least three pieces of evidence.

A reasonable claim is that at any given mass, an endotherm has a much higher metabolic rate than does an ectotherm. A broad range of data points could be used to support this claim. For example, a partridge (endotherm) and a Gila monster (ectotherm) have approximately the same mass, but the partridge's metabolic rate is more than 100 times greater. Other animal pairs that support this claim are pythons or alligators (ectotherms) versus ravens (endotherms); sandbar sharks (ectotherms) versus rabbits (endotherms); and saltwater crocodiles (ectotherms) and horses (endotherms).

6. Fossils are our only link to dinosaurs—we cannot observe their internal temperatures directly, nor can we analyze their soft tissues or DNA. What ideas do you have for the kinds of evidence you could collect from fossils that might allow you to make a claim about whether dinosaurs were ectothermic or endothermic?

This question serves as a pre-reading question that will be answered for students in the reading in Part 2, and it also serves to make an important point about the practice of science. Scientists cannot directly measure whether dinosaurs were ectotherms or endotherms as they can in living animals like the cheetah. However, studies with living animals show that mass and metabolic rate can reliably predict ecto- and endothermy. If scientists can use fossil evidence to measure mass and metabolic rate, they could use these data as proxies to determine if dinosaurs were endotherms or ectotherms.

PART 2: ESTIMATING DINOSAUR GROWTH AND METABOLISM



Short Film
Great Transitions: The Origin of Birds

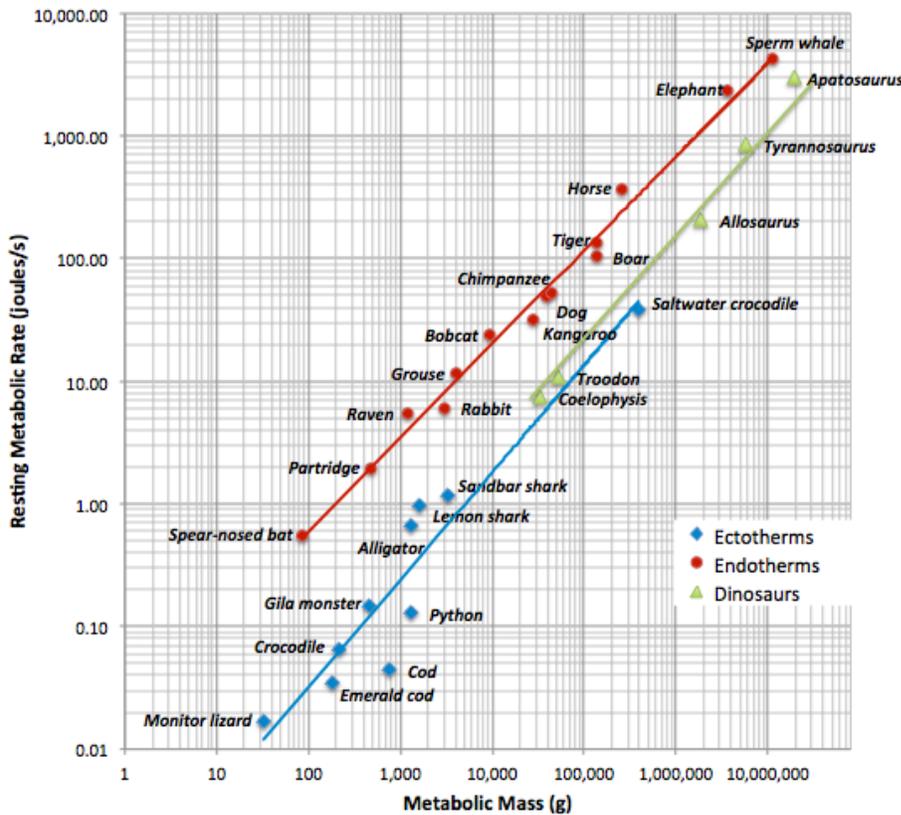


Figure 2a. The graph shows the approximate placements for the data in Table 2 of the student handout.

7. From the reading, summarize the evidence that scientists use to estimate the mass and the metabolic rate of dinosaurs.

Scientists use two types of evidence from fossil bones to estimate mass and metabolic rate. Bone size is used to estimate the overall mass of a dinosaur. Growth ring width is used to estimate the growth rate of a dinosaur, which can be used to estimate the metabolic rate.

8. Explain why a mouse has wider rings in its bones than a lizard.

Because mice have a faster growth rate, they will add more bone over the course of a year than a lizard, which has a slower growth rate. As a result, the mouse has wider growth rings in its bones.

9. As the masses of the dinosaurs increase, how do their metabolic rates change? How does this compare to living animals?

Students should note that as with living animals, the higher a dinosaur's mass, the higher its metabolic rate.

10. Draw a line of best fit through the endotherms, through the ectotherms, and through the dinosaurs. Make a claim about whether the relationship between mass and metabolic rate in



dinosaurs follows a pattern more similar to ectotherms or endotherms. Support your answer with evidence.

The metabolic rates in dinosaurs are not quite as high as those of endotherms of similar mass, but they are a bit higher than those of ectotherms of similar mass.

11. *Based on the graph, which animal would you expect to have wider rings in its bones: a mountain lion or a type of dinosaur called a Troodon? Troodons were about the same mass as mountain lions and looked like feathered velociraptors. Explain your answer.*

Students should say a mountain lion because it has a higher metabolic rate.

Part 3: THE ENERGETICS OF DINOSAURS

12. *In the graph in Figure 3, which types of animals have the highest growth rate? Which have the lowest?*

Highest: endotherms; lowest: ectotherms

If you would like to make a further math connection, you may want to explain to students how the units in the graph were derived. Growth rate is measured as grams per day = g/d. The unit for metabolic rate is joules per second = watts = W. Growth and metabolic rate scale approximately as $\text{mass}^{3/4}$, so dividing mass out of each value removes the effects of mass.

For growth rate, g/d becomes $\text{g/d/g}^{3/4} = \text{g}^{(4/4 - 3/4)}/\text{d} = \text{g}^{1/4}/\text{d}$. The unit for weight-independent growth rate is therefore $\text{g}^{1/4}/\text{d}$.

For metabolic rate, the unit for weight-independent metabolic rate is simply $\text{W/g}^{3/4}$.

13. *In the graph, which types of animals have the highest resting metabolic rate? Which have the lowest?*

Highest: endotherms; lowest: ectotherms

14. *As the resting metabolic rate increases, how does the growth rate change?*

As the resting metabolic rate increases, the growth rate increases. At higher metabolic rates, animals can grow faster.

15. *In their paper, Grady and colleagues conclude that dinosaurs were mesotherms (meso- means "middle"). Compare the growth rates of dinosaurs with the growth rates of living ectotherms and endotherms. Why do you think these scientists describe dinosaurs this way, and do you agree with their conclusion? Refer to specific data points to support your answer.*

Students should say that dinosaur growth rates were higher than those of living ectotherms, but lower than living endotherms. Students should relate the prefix meso- and its meaning ("middle") to the idea that dinosaurs had metabolic and growth rates higher than ectotherms but lower than endotherms—in other words, metabolically, they were in the middle of ectotherms and endotherms.

16. *Grady and colleagues made their data available to all other scientists. One scientist reanalyzed their data using some different assumptions and came to an alternative conclusion. This scientist also carefully described the methods he used for his calculations. Grady and colleagues reviewed*



Short Film
Great Transitions: The Origin of Birds

the work of the other scientist and replied with an argument about why their method of calculating metabolic rates was correct. Describe how these events exemplify how science works.

Students may note how the practices of making data and methods of analysis available for other scientists to review, developing alternative explanations of evidence, and making arguments based on evidence, as well as the tentative nature of all scientific claims, are examples of how science works.

Part 4: THERMOREGULATION IN DINOSAURS

17. *From an evolutionary point of view, how could being mesothermic have been an advantage for dinosaurs as compared to being ectothermic or endothermic?*

Students should respond with ideas such as if dinosaurs were mesotherms, they could grow faster and move faster than similarly sized ectotherms while requiring less energy intake (i.e., food) than similarly sized endotherms.

18. *In the previous question, you described how being mesothermic can be an advantage. Why do you think that more animals are not mesotherms at this point in time?*

This question is designed to help students consider the costs of being mesothermic and not only the benefits. Some potential costs are that mesotherms could be outcompeted for prey by similarly sized endotherms in similar niches. They may also require more additional sources of energy compared to ectotherms, which would put them at a competitive disadvantage if energy was a limiting factor for growth.

19. *The HHMI film presented research findings that support the idea that birds evolved from theropod dinosaurs. Much of the information in the film focuses on structures in the body that were either more reptile-like or more bird-like. How do the data in this activity add to your understanding of the relationship between dinosaurs and birds?*

The data in this activity are evidence that dinosaurs were more similar to birds in the way they control their body temperatures than scientists initially thought. The ability to control internal body temperature had started to evolve in dinosaurs, just like feathers and other features.

REFERENCE

Grady, John M., Brian J. Enquist, Eva Dettweiler-Robinson, Natalie A. Wright, and Felisa A. Smith. "Evidence for Mesothermy in Dinosaurs." *Science*, 344, no. 6189 (2014): 1268–1272.

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