How Did Dinosaurs Regulate Their Body Temperatures?

Activity
Educator Materials

OVERVIEW

This activity extends concepts covered in the short film *Great Transitions: The Origin of Birds*. Students analyze and interpret data from a scientific paper to explore thermoregulation in living and extinct animals, including dinosaurs.

The activity challenges students to use data to investigate the following question raised in the film: How did dinosaurs regulate their body temperature? Students will consider whether body temperature regulation in dinosaurs was more like that in birds (endotherms), reptiles (ectotherms), or something in between. In the process, they will learn about the methods used to determine animals' metabolic rates and will analyze, interpret, and graph scientific data.

Additional information related to pedagogy and implementation can be found on this resource's webpage, including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

- Resting metabolic rate is the minimum amount of energy an animal has to expend, at rest, to maintain life processes.
- Since growth is a result of metabolic activity, resting metabolic rate is directly related to growth rate (how much an animal grows per unit of time). The higher the metabolic rate, the faster the growth rate tends to be.
- Animals range from ectothermic to endothermic, depending on how they maintain and regulate their internal body temperatures. Ectotherms have lower resting metabolic and growth rates than do endotherms of similar size.
- Fossilized bones contain information that can be used to estimate resting metabolic rates and growth rates of dinosaurs.

STUDENT LEARNING TARGETS

- Analyze and interpret scientific data.
- Make claims based on evidence from scientific data.
- Participate in a collaborative discussion about the evidence with classmates.

PRIOR KNOWLEDGE

Students should be familiar with:

- basic concepts of common ancestry
- transformation and conservation of energy, especially as it relates to cellular respiration
- interpreting graphs that use logarithmic scales

TEACHING TIPS

- Students may watch the film *Great Transitions: The Origin of Birds* either before or after engaging with this activity. This activity can also be done independently of the film. If students watch the film, have them pay particular attention to any mention of metabolism or "warm-/cold-bloodedness."
- 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,

the blood of a snake basking in the sun could, at that moment, be warmer blood than that of a human. As a result, scientists prefer to classify animals based on the source of their heat ("endothermic" for internal sources and "ectothermic" for external sources).

  - In addition, animals can be distinguished by how stably they maintain their internal body temperatures. The terms "homeotherms" (animals that maintain a somewhat constant internal temperature), "poikilotherms" (animals whose internal temperatures can vary widely), and "heterotherms" (animals that can switch between homeothermic and poikilothermic strategies on a daily or annual basis) are not used in the activity, but if students are familiar with them already, they can be helpful tools in talking about thermoregulation.

- The "Student Handout" contains some passages of relatively high reading levels, which could be challenging to some students. Provide sufficient time to read and additional support, such as a glossary, as needed.
- If students need some extra time to go over the basics, you may find it helpful to have students read Part 1 and ask questions as a group before continuing the activity.
- You may want to pass out each part of the activity separately, because later parts give away answers to some questions in earlier parts.
- After students complete each part of the activity, consider conducting a brief class discussion of the answers. This will help students follow from one part to the next.
- Figures 2 and 3 in the "Student Handout" use color to distinguish between ectotherms and endotherms. If the handouts are printed in black and white, you can share the color images with students online or display them using a projector. Alternatively, you can tell students which animals are ectotherms/endotherms and have students mark them accordingly in the figures.
- Figures 2 and 3 in the "Student Handout" are log-log graphs (have logarithmic scales on both axes). If students are unfamiliar with interpreting such graphs, consider discussing them as a class.
  - It may be helpful to show students how some of the points were plotted. For example, in Figure 2, the emerald cod has a mass of nearly 180 grams, so its point is between the line labeled 100 on the *x*-axis and the next line to the right, which represents 200. The cod's metabolic rate is 0.035, so its point is slightly above 0.03 on the *y*-axis, which is two lines up from the line labeled 0.01.
  - If students are comfortable with logarithms, you may wish to explain that these graphs are log-log graphs, and that a linear relationship on a log-log graph is indicative of a power function. (In other words, straight lines on a log-log graph correspond to curved lines when plotted on a linear scale.) For example, the linear relationship between metabolic rates and mass in Figure 2 indicates that metabolic rates increase as a power function of mass.
- Figure 3 in the "Student Handout" uses mass-independent units for the graph's axes. If students have questions about what this means, you can explain that it reflects a mathematical transformation of the growth and metabolic rates that removes the effects of mass. If students are comfortable with power functions and dimensional analysis, you may want to give a more detailed explanation of how the units in the graph were derived, as follows:
  - Growth rate can be measured in grams per day (g/d). Metabolic rate can be measured in joules per second, which is equivalent to watts (W).
  - Growth and metabolic rates scale approximately as mass$^{3/4}$. Mass can be measured in grams (g).
  - To get the mass-independent rates, which remove the effects of mass, divide the units of each rate by the unit of mass$^{3/4}$ ($g^{3/4}$). Thus:
    - The unit for the mass-independent metabolic rate is $W/g^{3/4} = Wg^{-3/4}$

    - The unit for the mass-independent growth rate is $(g/d)/(g^{3/4}) = g^{(4/4-3/4)}/d = g^{1/4}/d = g^{1/4}d^{-1}$.

- Question 5 in Part 4 of the "Student Handout" mentions another scientist who reanalyzed the data and came to an alternative conclusion. 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 may be reached.
    - The main contention of the scientist who reanalyzed the data, Michael D'Emic of Stony Brook University, is that because dinosaurs displayed seasonal growth, the growth rate estimates calculated by Grady and colleagues should be doubled. D'Emic's calculations suggest that dinosaurs were endotherms rather than mesotherms (D'Emic 2015).
    - In their response, Grady and colleagues maintained that nonavian dinosaurs were mesotherms. They pointed out that most animals also show seasonal growth, so if they doubled the rates for dinosaurs, they would also have to do so for other groups in the analysis, leading to no change in the overall results (Grady et al. 2015).

ANSWER KEY

PART 1: Thermoregulation in Living Animals

1. Would you expect any differences between the body temperatures of these animals and the temperatures of their environments? Is your answer the same for all the animals? Why or why not?

   This is a prereading question that helps students anticipate the rest of Part 1. 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 those of their environments, whereas the endotherms may have internal temperatures that differ significantly from external temperatures.

2. Define "ectotherm" and "endotherm" in your own words. List four examples of animals that would fit into each category.

   Students should recognize that the body temperatures of ectotherms are mostly determined by the outside environment, whereas endotherms rely on heat generated inside their bodies to regulate temperature. For the examples, be open to a range of responses. In general, amphibians and most reptiles, fish, and invertebrates are ectotherms, whereas mammals and birds are endotherms.

3. According to the law of conservation of energy (or the second law of thermodynamics), energy cannot be created or destroyed. However, energy *can* be transformed. Summarize some of the transformations of energy described in the paragraphs above.

   Some of the transformations of energy mentioned are chemical energy in food being converted into heat and into energy for doing biological work, such as growth, movement, or reproduction. Energy is also transformed during shivering, when muscles contract rapidly and use energy to produce heat.

4. Predict whether dinosaurs were more like endotherms or ectotherms. Support your prediction with evidence from the paragraphs above and your own knowledge.

   Student answers may vary; be open to a range of logical responses. This question is meant to help engage students and motivate them to complete the rest of the activity.

PART 2: Metabolism and Mass of Living Animals

1. Based on the general trends in Figure 2:
    a. How do the metabolic rates of ectotherms compare with those of endotherms of similar mass?

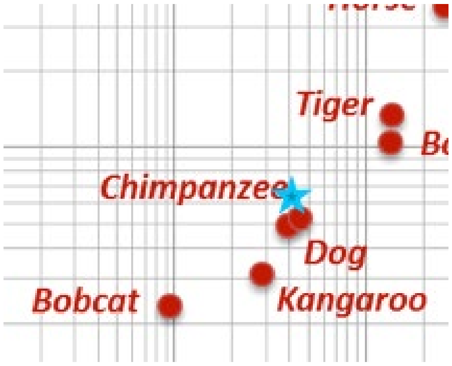
       At a given mass, resting metabolic rates of endotherms are higher than those of ectotherms.

b. How do the metabolic rates of both ectotherms and endotherms vary with mass?

For both ectotherms and endotherms, animals with larger mass tend to have higher resting metabolic rates.

2. An average adult cheetah has a metabolic mass of 44,010 grams and a resting metabolic rate of 61.77 joules per second. Use this information to add a data point for the cheetah to Figure 2. Based on these data, would you characterize the cheetah as an ectotherm or endotherm? Support your answer with evidence from the graph.

   Students should plot the cheetah's point slightly above those of the chimpanzee and dog, as indicated by the blue star to the right. They should conclude that a cheetah is an endotherm because its position on the graph is similar to those of the other endotherms.



3. Briefly describe other data you could collect to provide additional evidence for whether the cheetah is an ectotherm or an endotherm.

   Student answers may vary. They may suggest measuring the internal body temperature of a cheetah in a range of external temperatures. If the body temperature of the cheetah stays relatively constant, this would provide more evidence that the cheetah is an endotherm.

4. As the masses of the animals increase, how do their metabolic rates tend to change? Answer this question for both ectotherms and endotherms.

   For both ectotherms and endotherms, metabolic rate tends to increase as mass increases. (Students may note that the correlation in ectotherms may not be as clear as it is for endotherms.)

5. Make a claim about how the metabolic rates of endotherms compare with those of ectotherms of similar mass. Support your claim with at least three pairs of data points from Figure 2.

   Student answers will vary. A reasonable claim is that an endotherm has a much higher metabolic rate than an ectotherm of similar mass. Many pairs of data points in Figure 2 could be used to support this claim. For example, the partridge (endotherm) and Gila monster (ectotherm) have approximately the same mass, but the partridge's metabolic rate is over 100 times greater. Other pairs that support this claim include the python/alligator (ectotherm) and raven (endotherm), the sandbar shark (ectotherm) and rabbit (endotherm), and the saltwater crocodile (ectotherm) and horse (endotherm).

6. What kinds of evidence from fossils might help determine whether dinosaurs were ectotherms or endotherms?

   This is a prereading question that helps students anticipate Part 3, and it also makes an important point about the practice of science. Because this question asks about students' initial ideas, be open to a range of responses. Students may suggest some way of using fossil evidence to estimate a dinosaur's mass and metabolic rate. These estimates can be compared with data from living animals, like in Figure 2, to determine whether dinosaurs are more similar to ectotherms or endotherms.

PART 3: Estimating Dinosaur Mass and Metabolism

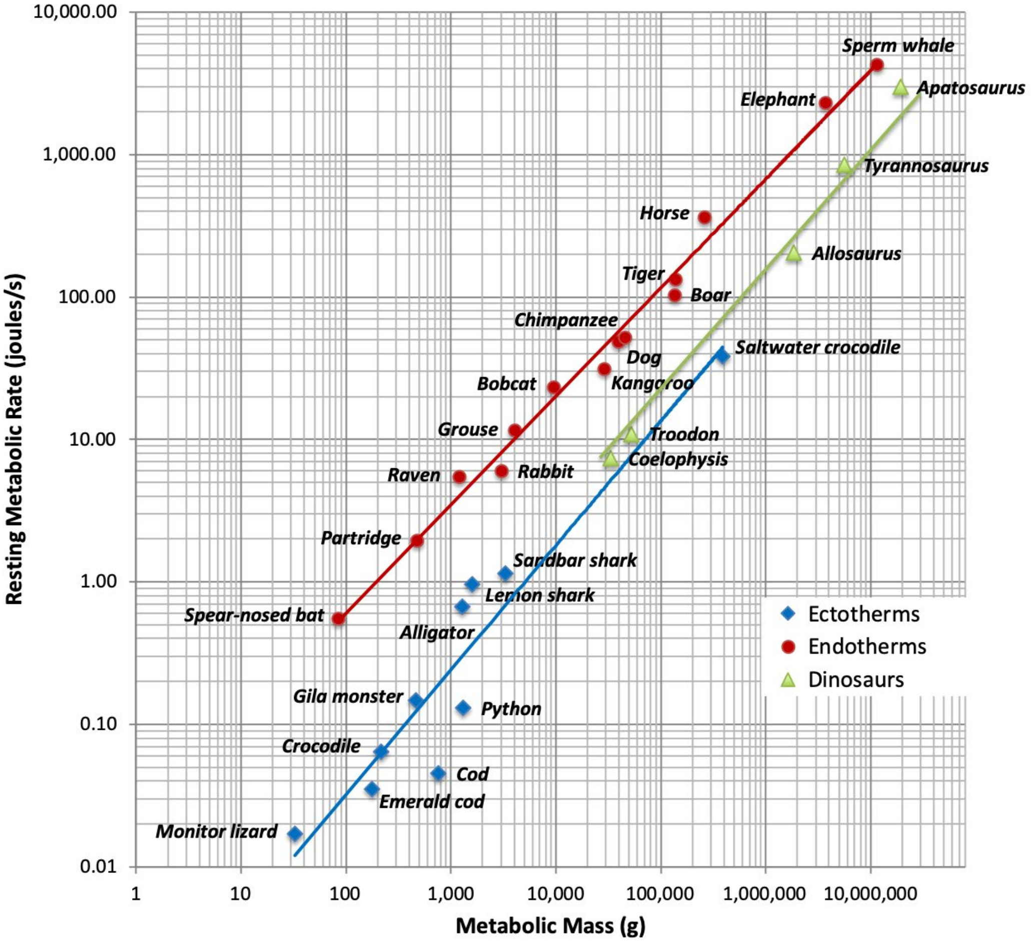
1. Summarize the evidence used to estimate the masses and the metabolic rates of dinosaurs.

   We can use bone size to estimate the overall mass of a dinosaur. We can use bone ring width to estimate the growth rate of a dinosaur, which can be used to estimate the dinosaur's metabolic rate.

2. Explain why a mouse (an endotherm) would probably have wider bone rings than a similarly sized lizard (an ectotherm).

Since the mouse is an endotherm, it probably has a higher metabolic rate, and thus a faster growth rate, than the lizard (an ectotherm of similar size) does. If the mouse has a faster growth rate, its bones would grow more between each ring, resulting in wider bone rings.

Plot the Table 2 data on Figure 2 (from Part 1 of the activity), then answer the questions below.
The graph below shows the data from Table 2 ("Dinosaurs") as green triangles. Lines of best fit for the endotherms, ectotherms, and dinosaurs are also shown.



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

   As with living animals, the higher a dinosaur's mass, the higher its metabolic rate.

4. Make a claim about whether the relationship between mass and metabolic rate in dinosaurs follows a pattern more similar to that of ectotherms or endotherms. Support your answer with evidence from the graph.

   Student answers may vary because the pattern in the dinosaur data is not completely similar to that of either ectotherms or endotherms. The graph shows that the metabolic rates of dinosaurs are not quite as high as those of endotherms of similar mass. However, they are also a bit higher than those of ectotherms of similar mass.

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

   A mountain lion should have wider bone rings because it has a higher metabolic rate, and thus a faster growth rate.

PART 4: The Energetics of Dinosaurs

1. Which types of animals have the highest mass-independent **growth** rates? Which have the lowest?

   Endotherms have the highest growth rates and ectotherms the lowest.

2. Which types of animals have the highest mass-independent **metabolic** rates? Which have the lowest?

   Endotherms have the highest metabolic rates and ectotherms the lowest

3. In general, as metabolic rate increases, how does growth rate change?

   As metabolic rate increases, growth rate increases. This means that animals with higher metabolic rates grow faster.

4. Compare the growth rates of dinosaurs to those of living ectotherms and endotherms. Why do you think the scientists described dinosaurs as "mesotherms," and do you agree with their conclusion? Use evidence from Figure 3 to support your answer.

   Student answers may vary. They should notice that dinosaur growth/metabolic rates were higher than those of living ectotherms but lower than those of living endotherms. Since meso- *means "middle," it indicates that dinosaurs likely had growth/metabolic rates in the "middle" of those for ectotherms and endotherms.*

5. Describe how these events are a good example of how science works.

   Student answers may vary. They may note several examples of science practices, such as making data and methods of analysis available for other scientists to review, developing alternative explanations of evidence, and making arguments based on evidence to support or revise scientific claims.

PART 5: Thermoregulation in Dinosaurs

1. How might being a mesotherm, rather than an ectotherm or endotherm, have been advantageous for dinosaurs?

   This question has students consider the potential benefits of being a mesotherm. They may suggest that being mesotherms allowed dinosaurs to grow and move faster than similarly sized ectotherms, while requiring less energy intake (i.e., food) than similarly sized endotherms.

2. Today, mesotherms are relatively rare. If being a mesotherm was advantageous for dinosaurs, why do you think there aren't more mesotherms now?

   This question has students consider the potential costs of being a mesotherm. They may suggest that mesotherms could be outcompeted for prey by similarly sized endotherms in similar niches. Mesotherms may also require more energy compared to ectotherms, which would put them at a competitive disadvantage if energy was a limiting factor for growth.

3. A lot of evidence suggests that birds evolved from theropod dinosaurs. How did the data in this activity add to your understanding of the relationship between dinosaurs and birds?

   Student answers may vary. If they watched the film Great Transitions: The Origin of Birds, they may mention the part of the film that said scientists initially thought dinosaurs were "cold-blooded and slow-moving" like reptiles and other ectotherms. The data in this activity show that dinosaurs actually had traits between those of ectotherms and endotherms, making them more similar to birds than scientists initially thought. This could even suggest that endotherm-like traits started to evolve in dinosaurs, just like feathers and other body structures did.

REFERENCE

D'Emic, M. D. "Comment on 'Evidence for mesothermy in dinosaurs.'" *Science* 348, 6238 (2015): 928. https://doi.org/10.1126/science.1260061.

Grady, John M., Brian J. Enquist, Eva Dettweiler-Robinson, Natalie A. Wright, and Felisa A. Smith. "Evidence for Mesothermy in Dinosaurs." *Science* 344, 6189 (2014): 1268–1272. https://doi.org/10.1126/science.1253143.

CREDITS

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- All others are from Grady et al. (2014) or original work.