Supplemental instructor materials for
SCIENTIFICALLY THINKING
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Prometheus Books, 2018

Discussion questions based on photographic images. All photos are by the author, Stanley A. Rice. The instructor can show these images to students and ask them to discuss and answer the answers to the questions provided, or to other questions generated by the instructor (or the students). These discussions should not only promote scientific thinking in students but also enhance their habit of *noticing* things in the world around them.

Figures 1 and 2.

What kinds of hypotheses could you test using tree rings? A tree forms a new ring of wood each year, outward from the center of the trunk. A ring consists of relatively large sap vessels produced in the spring (light-colored wood) and relatively small sap vessels produced in the summer (dark-colored wood). A ring is therefore a band of wood, half of which is light, and half of which is dark.

- About how many years old was the tree on the left when it died? [Instructor: not all the rings are visible in the photo; students will have to estimate.]
- One of these trunks is from the fast-growing red oak; the other is from the slow-growing post oak. Which one is which?
- Can you tell exactly how old the tree on the right was when it died?
- What kind of information can you get from the fact that some of the rings are thicker than others? This is true of both examples, but is more easily seen in the sample on the left.
- Instructor: A thick ring of wood means a good year, a thin ring means a bad year, for tree growth. In a hot dry forest, a thick ring means a wet summer; in a colder, wet forest, a thick ring means a warm summer. You can discuss the construct validity (Chapter 11) of tree rings as a record of past climates.

Figure 3.

This activity gives practice with hypothesis formation (Chapter 1). This is a “fairy ring” of mushrooms. According to folklore, magical little people dance in the middle of it. In order to generate a scientific hypothesis about how fairy rings form, you need some background information. In particular:

- Most of the fungus consists of invisible (to you) strands that grow through the soil and digest leaf litter and dead wood. After a few years, the strands deplete the soil of the nutrients that it needs, especially nitrogen. They get nutrients mainly at the leading edge of the growth of the strands.
- Mushrooms form when fungal strands fuse together, and they do so mostly in locations in which the soil is rich.
- Fairy rings form in woodlands, lawns (which is where you usually see them), and grasslands.

Given this information:

- Generate a scientific hypothesis for how a fairy ring forms.
- The fairy ring looks like it has formed around the base of a tree that is no longer present. Does this have to always be the case?

Figure 4.

What happened here in this yard?

- Is it possible that this might be a fairy ring? Fungal strands, by digesting dead grass and wood, sometimes liberate enough mineral nutrients such as nitrogen that they cause the grass to become greener. You can sometimes see a fairy ring as a ring of green grass from which the mushrooms have not yet emerged. If so, why is the middle barren?
- If this is not a fairy ring, what might it be? Be as specific as possible. (Note to instructor: male dog or female dog?) Note that this picture was taken in a lawn next to apartment buildings. Your alternative explanation should include both why the ring is green and why the middle is barren.
- Instructor: This activity provides practice with thinking of previously-overlooked factors to generate alternative hypotheses (Chapter 12).

Figure 5. The instructor can have students search online (or in a book??) for information about the life and work of George Washington Carver and share their discoveries with the class. The author's explanation for why Carver is his favorite scientist is in Chapter 20. See also the author's Darwin Channel video at: http://youtu.be/okynvvXcOGQ.

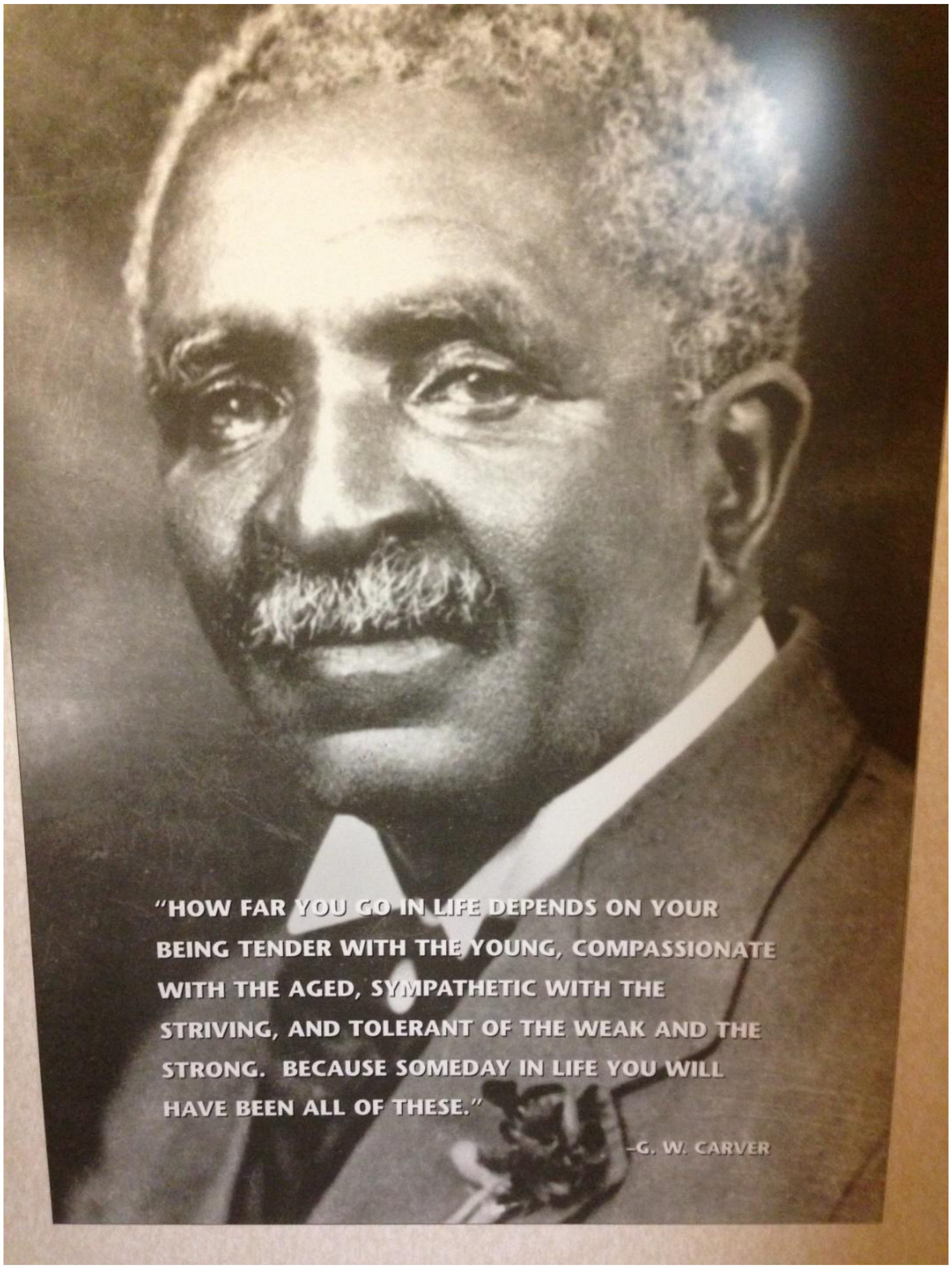


Figure 6. Fossilized bones of horses at Ashfall Beds State Historic Park in northeastern Nebraska. It's sort of an out-of-the-way place, but worth the time to visit! See the author's Darwin Channel video at: https://youtu.be/gSKaBEWrLy4.

- Usually fossils form in sediments at the bottom of rivers, lakes, or shallow seas. When this happens, the bones are usually disarticulated (that is, they fall apart from one another and scientists have to put them back together). But here, the bones are all in place? How did this happen? Hint: the matrix around the bones is volcanic ash.
- The volcanic ash is very fine. There are no coarse ash particles. What does this tell you about the location of the volcano that produced it? That is, how far away would the volcano have been, and would it have been to the east, or to the west?
- Why did they so many animals come to this one place? Hint: When an animal breathes in fine volcanic dust, it gets very thirsty.

- This deposit formed 12 million years ago. At that time, the savannas of North America had many species of animals that are no longer native to the region, including hippopotamus and camel. What happened to these animals? Is this true even of the horses? Note: modern wild horses in America are the descendants of horses that escaped from the Spaniards about four hundred years ago.
- There are five species of horses in Ashfall Beds. Some of them have multiple toes. How does this compare with modern horses, and what do the twelve-million-year-old skeletons of multiple-toed horses tell you?

Figure 7. Aspen trees *(Populus tremuloides),* such as this tree in Wyoming, grow very rapidly. You can see, in this photo, one of the reasons. Notice the outer bark of aspen bark is thin, tight, and white, with a green layer of cortex underneath it. Do all trees have this adaptation?

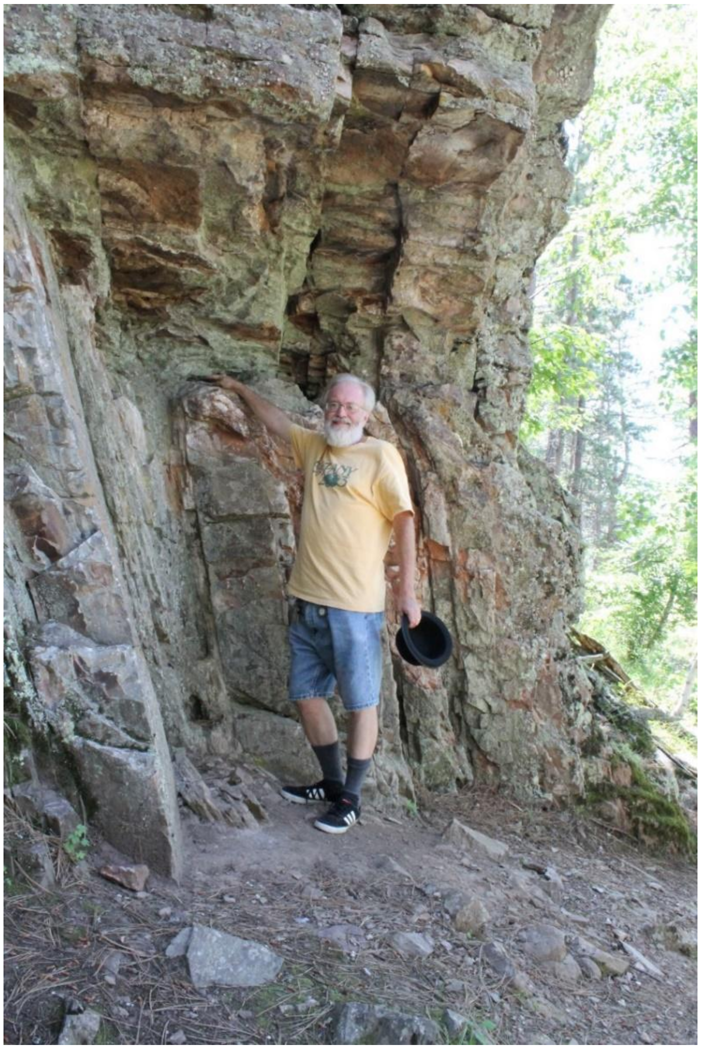
Figure 8. This “leaf fossil” was formed 15 million years ago in what is today Idaho (at Fossil Bowl near the little town of Clarkia). This and thousands of other leaves like it were buried by sediments in a shallow lake. The water had little oxygen, so the leaves did not decompose very much. The loose sediments can today be pried apart with a knife, revealing the leaves. (You can see a video of the son of the land owner splitting open the sediment layers on the author’s Darwin Channel; the direct link to the video is here [http://youtu.be/ml4oT5zuiBk]. The leaves are often reddish when first exposed to the air, after which exposure to oxygen rapidly turns them into black charcoal. Therefore, this leaf is not really a fossil; fossils form when minerals replace the original molecules of the dead organ or organism. But the carbon atoms of this leaf were actually in the original leaf. Most leaf fossils are just impressions that the now-decomposed leaf left in the sediments. This photo shows a leaf from an extinct species of sweetgum (three-lobed leaf below the author’s thumb) and a beech leaf (inverted, upper right). Discussion questions are on the next page.

Discussion questions for Figure 8.

- What could you learn from this leaf that you could not from just a fossil impression? (Note that the organic molecules quickly turn to charcoal upon exposure to air.)
- This leaf is from a now-extinct species of sweetgum tree. Today, sweetgums do not grow in Idaho. They grow in Asia and eastern Europe, and in southeastern North America. Why did they become extinct in Idaho during the last 15 million years? Think about how the climate is different in Idaho from these other places, in terms of moisture and temperature (Idaho is mostly high elevation).
- What caused Idaho's climate to change? Note: the Cascade Mountains, to the west, were formed by volcanic eruptions mostly during the last 15 million years, and volcanic dust can be found in some of the sediment layers at Fossil Bowl.
- What evidence might you expect to verify the hypothesis that the leaves were buried in sediments with very little oxygen? Note that these sediments still smell like hydrogen sulfide when they are first exposed.

Figures 9 and 10. This is a close-up of petrified wood from Petrified Forest National Park in Arizona. Over 250 million years ago, this was the wood of a living tree that fell into water and decomposed slowly. Today, it consists of rock minerals, which includes metal ions that create colors that were not originally present in the wood. You can still see the wood grain. Have your students explain how the wood became petrified. There are entire logs of petrified wood. The trees, genus *Auracarioxylon*, are now extinct. See the author's Darwin Channel video at: http://youtu.be/-NGZ3YlvxWY.

Figure 11. The author is standing beside the Great Unconformity in the Black Hills of South Dakota. How did these rock layers form? Notice that the bottom layers are tilted about sixty degrees, while the top layers are horizontal. There is about a billion years missing from these layers, right about where the author's finger is pointing. See the author's Darwin Channel video at: http://youtu.be/X4ZP9NtpPEA.



- How did the bottom layers of sediments form? What was their orientation when they formed?
- What caused the layers to turn sixty degrees on their sides? (Note: a good chance to discuss continental drift.) Did the sediments have to be solid rock at the time this happened? Note that no sediments were accumulating at the time this happened.
- Then what happened to form the upper layers of sediments?
- What happened after the upper layers were formed? Note: today they are solid rock and this deposit is now over four thousand feet above sea level.

Figure 12. This is the oak tree *Quercus gravesii,* the Graves' oak, here shown in the Chisos Mountains of Big Band National Park. It grows only in ravines and at the bottoms of cliffs high in the desert mountains of extreme southwest Texas and nearby areas of northern Mexico (see the Wikipedia distribution map). At lower elevations in these mountains, and all around these mountains, the landscape is desert shrubland. The gray oak, *Quercus grisea,* has a similar story, as told in the author's Darwin Channel video at: http://youtu.be/EKtx05KUh4E.

How did this oak get to the top of desert mountains? Note that (1) the climate has gotten drier during the last ten to twenty million years; (2) the closest relatives of this species, red oaks, grow in the deciduous forests of the United States. You can also find populations of limber pine (an alpine species of pine found mostly in the western mountains of North America), and sugar maple in the Chisos Mountains.

Figure 13. These sugar maples are growing near Tulsa, Oklahoma. Sugar maples are very rare in Oklahoma. They are abundant in the eastern deciduous forest north and east of Oklahoma. Why are sugar maples found in this particular location? Note that they are growing at the base of north-facing cliffs. Think of as many reasons as you can.

Figure 14. Why is this twig melting into the snow? Explain the steps that have caused this to happen. Does snow absorb very much sunlight? Does the twig absorb very much sunlight? Note that the sun is shining in this photo.

This photo can also accompany a discussion of Chapter 9 of *Scientifically Thinking*. Global warming can cause snowmelt, which can result in a "vicious circle" of global warming and snowmelt. This photo allows students to notice something that many of them have seen but never thought about and which confirms the vicious-circle aspect of global climate change.

Figures 15 and 16. These are the *Phacelia strictiflora* wildflowers that grew abundantly after the forest fire as described in Chapter 1 of *Scientifically Thinking*. These are the plants on which we tested the hypothesis that smoke chemicals are necessary for seed germination. The instructor can discuss the experimental procedure with students. Part of this experimental procedure is to produce smoky water in which to germinate the seeds. See how this was done in the Darwin Channel video at: http://youtu.be/1bnJa7yYkyM.

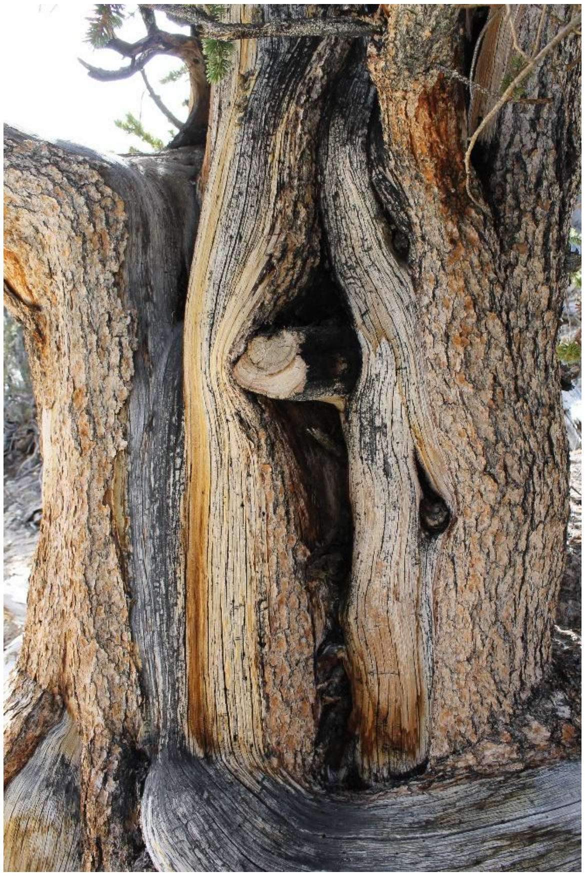
Figure 17. This rock is gypsum (calcium sulfate) that formed millions of years ago at the bottom of a shallow sea that once covered northwestern Oklahoma. Gypsum is white and translucent (that is, light can shine through thin layers of it). What is the green layer just below the surface of the gypsum? Note that it is not inorganic (e.g. an inorganic copper compound), but is organic and consists of living cells. What are the cells and why do they grow exactly where they do?

Figure 18. What are the fuzzy balls on these post oak leaves? The leaves have been shed by the tree.

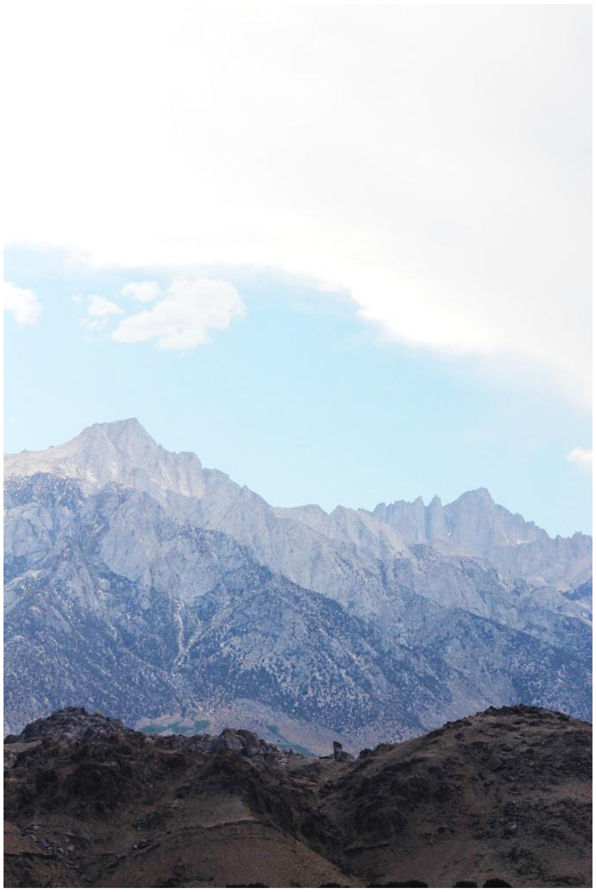
- Grubs of parasitic wasps have formed these “insect galls.” The adult wasps hatch from the galls. But the galls do not consist of insect tissue. The grubs release molecules that affect plant growth. Now, explain how these fuzzy balls formed.
- What would be the advantages to the wasp grub to stimulate gall formation, rather than just eating the leaf tissue?
- What can the tree do to get rid of the galls?

Figure 19. This kind of caterpillar eats the leaves of black cherry trees. They form a dense tent of webs, and hide inside of them during the day. They come out at night to eat the leaves. Why, then, are these four caterpillars outside of the tent? Note: these caterpillars would occasionally twitch. Have your students read about parasites that alternate between caterpillar and bird hosts, then have them explain what happened to the caterpillars and the advantage that this provides to the parasite.

Figures 20 and 21. Bristlecone pines *(Pinus longeava)* such as this one live in the White Mountains of California, where the winters are long and cold, the summers cool and dry, and the soil is very poor. How do these trees survive? See also the Darwin Channel video at: http://youtu.be/eTmSI_QwtR8.



Figures 22 and 23. Figure 22 shows the Sierra Nevada mountains in California from Owens Valley on the east side. The peaks in this view include Mt. Whitney, which is the tallest mountain in the United States outside of Alaska. At this same elevation on the west slope, there is a thick forest of conifers, as shown in Figure 23, which also includes Mt. Whitney. But on this east slope, there is only desert. Have your students explain why the two sides of the mountain are so different. Hint: Where does the rain and snow come from? See also the Darwin Channel video at: http://youtu.be/uyD32fMfTLM.



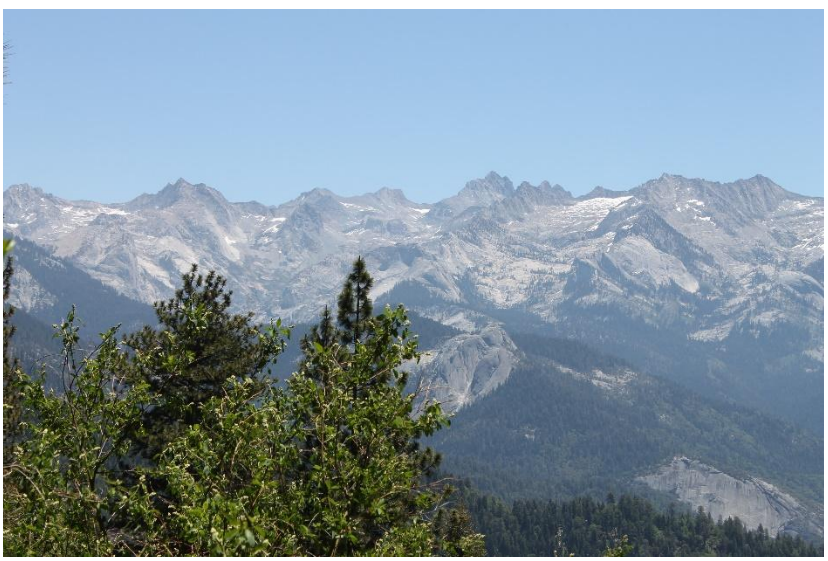


Figure 24. The California pine forest in the distance consists of a single species of pine *(Pinus muricata)* and all the trees are the same age (about 17 years old). How did this happen? And how are the pines adapted to take full advantage of the cause of this event? Note that the cones (on the tree in the foreground) are very dense and they do not open up and drop seeds out the way most pine cones do, unless the event that created this forest occurs. [Hint for instructor: the event is fire. A 2005 fire created this forest as seen in 2012. The cones will not open without fire.] See also the Darwin Channel video at: http://youtu.be/xowPbBi5bl0

Figure 25. This is a savanna of California black oaks *(Quercus kelloggii)* and grasses below Sequoia National Park in California. Most of the trees are growing on just one side of the hills. Which side are the trees growing on and why? (Hint: grasses tolerate drought better than oak trees do.) (Another hint: the photo was taken near the Kaweah River.)

Figures 26 and 27. This tiny wildflower *(Linanthus montanus)* grows only on gravelly granite outcrops in the Sierra Nevada Mountains of California where the soil is very shallow. Why?

Figures 28 and 29. These giant saguaro cacti in Arizona produce their large flowers only at the very top of the column. Can you think of an advantage this might provide to them? (Hint: pollination is only effective if pollen is carried from the flower of one plant to the flower of another plant of the same species.)