The Measure of Eratosthenes

Carl Sagan

A professor of astronomy at Cornell University, Carl Sagan has worked on a number of NASA projects and has completed extensive research on the possibility of life on other planets. He has done much to popularize the study of science and is especially well known as a result of having hosted the public television series Cosmos. *Among his most widely read books are* The Dragons of Eden, *for which he won the Pulitzer Prize in 1977,* Broca's Brain, *and* Cosmos.

Sagan published "The Measure of Eratosthenes" (er-uh-TAHS-thuh-neez) to honor an ancient Greek thinker who, seventeen centuries before Columbus, accurately measured the Earth and proved that it was round.

LOOKING AHEAD

1. In paragraph 4, Sagan claims that "in almost everything, Eratosthenes was 'alpha.' " Alpha is the first letter of the Greek alphabet.
2. Papyrus, mentioned in paragraph 5, is a plant from which paper was made in ancient times.

VOCABULARY

cataract Large waterfall.
circumference Distance around a circle or globe.
compelling Difficult to ignore.
deduced Concluded, discovered.
inclined Slanted.
intergalactic Between galaxies.
intersect Cross.
musings Thoughts.
pronounced Significant.
randomly By chance.

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The earth is a place. It is by no means the only place. It is not even a typical 1
place. No planet or star or galaxy can be typical, because the cosmos is mostly empty. The only typical place is within the vast, cold, universal vacuum, the everlasting night of intergalactic space, a place so strange and desolate that, by comparison, planets and stars and galaxies seem achingly rare and lovely.

If we were randomly inserted into the cosmos, the chance that we would find our- 2
selves on or near a planet would be less than one in a billion trillion trillion (10^{33}, a one followed by 33 zeros). In everyday life, such odds are called compelling. Worlds are precious.

The discovery that the earth is a *little* world was made, as so many important human 3
discoveries were, in the ancient Near East, in a time some humans call the third century B.C., in the greatest metropolis of the age, the Egyptian city of Alexandria.

Here there lived a man named Eratosthenes. One of his envious contemporaries 4
called him "beta," the second letter of the Greek alphabet, because, he said, Eratosthenes was the world's second best in everything. But it seems clear that, in almost everything, Eratosthenes was "alpha."

He was an astronomer, historian, geographer, philosopher, poet, theater critic, and 5
mathematician. His writings ranged from "Astronomy" to "On Freedom from Pain." He was also the director of the great library of Alexandria, where one day he read, in a papyrus book, that in the southern frontier outpost of Syene (now Aswan), near the first cataract of the Nile, at noon on June 21 vertical sticks cast no shadows. On the summer solstice, the longest day of the year, as the hours crept toward midday, the shadows of the temple columns grew shorter. At noon, they were gone. A reflection of the sun could then be seen in the water at the bottom of a deep well. The sun was directly overhead.

It was an observation that someone else might easily have ignored. Sticks, shadows, 6
reflections in wells, the position of the sun—of what possible importance could such simple, everyday matters be? But Eratosthenes was a scientist, and his musings on these commonplaces changed the world: in a way, they made the world.

Eratosthenes had the presence of mind to do an experiment—actually to observe 7
whether *in Alexandria* vertical sticks cast shadows near noon on June 21. And, he discovered, sticks do.

Eratosthenes asked himself how, at the same moment, a stick in Syene could cast no 8
shadow and a stick in Alexandria, far to the north, could cast a pronounced shadow.

Consider a map of ancient Egypt with two vertical sticks of equal length, one stuck 9
in Alexandria, the other in Syene. Suppose that, at a certain moment, neither stick casts any shadow at all. This is perfectly easy to understand—provided the earth is flat. The sun would then be directly overhead. If the two sticks cast shadows of equal length, that also would make sense on a flat earth: the sun's rays would then be inclined at the same angle to the two sticks. But how could it be that at the same instant there was no shadow at Syene and a substantial shadow at Alexandria?

The only possible answer, he saw, was that the surface of the earth is curved. Not 10 only that: the greater the curvature, the greater the difference in the shadow lengths. The sun is so far away that its rays are parallel when they reach the earth. Sticks placed at different angles to the sun's rays cast shadows of different lengths. For the observed difference in the shadow lengths, the distance between Alexandria and Syene had to be about seven degrees along the surface of the earth; that is, if you imagine the sticks extending down to the center of the earth, they would intersect there at an angle of seven degrees.

Seven degrees is something like one-fiftieth of 360 degrees, the full circumference of 11
the earth. Eratosthenes knew that the distance between Alexandria and Syene was approximately 800 kilometers, because he had hired a man to pace it out.

Eight hundred kilometers times 50 is 40,000 kilometers; so that must be the cir- 12
cumference of the earth. (Or, if you like to measure things in miles, the distance between Alexandria and Syene is about 500 miles, and 500 miles times 50 is 25,000 miles.)

This is the right answer. 13

Eratosthenes' only tools were sticks, eyes, feet, and brains, plus a taste for experi- 14
ment. With them he deduced the circumference of the earth with an error of only a few percent, a remarkable achievement for 2,200 years ago. He was the first person accurately to measure the size of a planet.

QUESTIONS FOR DISCUSSION

1. What does paragraph 6 tell us about the purpose for which Sagan wrote this essay?
2. Where does Sagan refer to the scientific process of making observations and of drawing conclusions from those observations?
3. Where does Sagan define important terms?
4. You have read that each step in a process should be discussed thoroughly. In what paragraph or paragraphs does Sagan's essay illustrate this principle?
5. Does this essay list separate steps in a process one by one? Explain your answer.
6. What methods of development, other than process analysis, does Sagan use?

THINKING CRITICALLY

1. Why does the author tell us so much about the life of Eratosthenes? Explain your answer in a short paragraph.
2. Make notes in the margins that explain each step in the process by which Eratosthenes measured the earth's circumference. Then put your notes into a well-organized paragraph.

SUGGESTIONS FOR JOURNAL ENTRIES

1. Make a brief, informal list of steps you might use to explain how a simple machine or natural process works. Pick something you have had experience with or know a lot about. Here are examples:

MACHINE	PROCESS
Sling shot	Circulation of the blood
Bow and arrow	Formation of rain clouds
Bottle opener	Photosynthesis
Cork screw	Osmosis
Food blender	Pollination of flowers by bees
Pliers	Transmission of a particular disease
Water wheel	Movement of the tides
Fishing reel	Formation of a fossil

2. Follow the advice in Suggestion 1 for a process that human beings have learned or invented to survive or to improve the quality of their lives. Examples include the process by which a broken bone is set, artificial respiration is given, an

incandescent bulb turns electricity into light, solar energy is used to heat a house, a serious disease is treated, or a food crop is grown or harvested.

3. Read about a scientist or inventor in an encyclopedia or other library reference book. Then, list steps he or she used to discover a scientific principle or to invent an important technique or product. Among those you might read about are Archimedes, Galen, Copernicus, Galileo, Kepler, Newton, Harvey, Galvani, Faraday, Pasteur, Curie, Marconi, Carver, Edison, Einstein, Bohr, and Fermi.