The Scientific Method (aka The Cycle of Proof)

The following story describes how Eratosthenes, the librarian of the Library of Alexandria in the third century B.C.E., was able to determine the size of the Earth.

First, read the story straight though. Then, look at the commentary, which refers to the sections of the story indicated by the superscript numbers, to see how the scientific research described in the story follows the scientific method, also known as the cycle of proof.

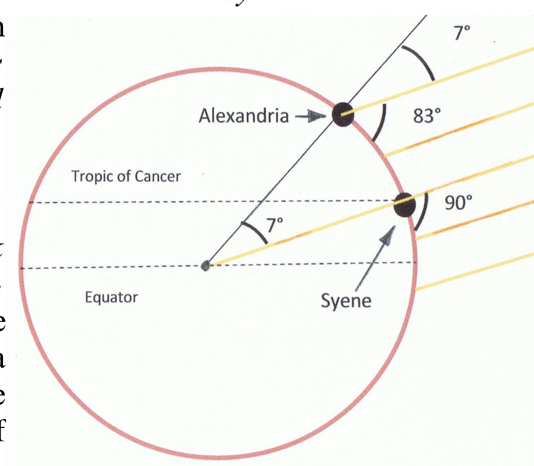
<u>How the Size of the Earth was Discovered</u>

Eratosthenes was a historian, geographer, and poet, but he was also notably a mathematician and astronomer. He was the first person to suggest that an extra day be introduced into the calendar every fourth year to keep the calendar in line with the seasons – our leap year.

In the library one day around 240 B.C.E., he was reading a papyrus book about Syene, a small town in the south of Egypt. One thing caught his attention in particular. *At noon on midsummer day in Syene, vertical sticks cast no shadow. Also, the sun shone straight down a deep well, so that its reflection could be seen by someone peering down the well into the water. Eratosthenes was puzzled. If that had ever happened anywhere he'd been, he thought, he'd surely have noticed it.*[1]

How could the sun, which Eratosthenes assumed was so far away that its rays were parallel, cast different shadows in different locations on the same day at the same time? *Eratosthenes reasoned that it was the Earth that must be curved.*[2] This idea of curvature, he realized, fitted in well with something else that people had always observed: if a ship had just disappeared over the horizon, it could still be seen by someone at the top of a nearby hill. It was for this reason that the lookout on a sailing ship was always sent up to the "crow's nest" at the top of the mast, high above the deck, to sight land.

Eratosthenes predicted that a vertical stick in Alexandria would cast a shadow at noon on midsummer day, and further, that the angle of the shadow could be used to determine what fraction of the Earth's curvature was represented by the distance between Alexandria and Syene.[3]



Eratosthenes set a man to pace the distance between Alexandria and Syene and *next midsummer day, Eratosthenes set up his vertical stick in Alexandria and watched and measured its shadow.*[4]

As the morning went on, the shadow became shorter. At noon, it wasn't very long, but it was still there. Eratosthenes measured the angle at the top of the stick between the end of the shadow and the stick. It was one-fiftieth of a complete circle – a little more than 7°.[5] So if the distance from Alexandria to Syene represents a fiftieth of a circle, then the distance around the world – the circumference – must be fifty times as far. Since in our units, his estimate of the distance between the two cities would be about 800 km, this would make the Earth's circumference 40 000 km, which we now know to be approximately the right answer.

Not everyone in Eratosthenes' time agreed with him. The ancients found it hard to accept that their known world was such a small fraction of the whole. Another Greek, Poseidonius, made another, smaller calculation of the circumference that was more accepted, and it was this calculation that Columbus used when planning his journey westward to India. If Columbus had known his journey was four times his estimate, he probably would never have started out. It was not until Magellan's expedition successfully circumnavigated the Earth that Eratosthenes was finally proved correct.

1. *The data base*. The second paragraph of the story describes what was already known before Eratosthenes began to think about what it meant. A great deal of scientific activity, not only then but also today, is concerned with gathering this data base: making and recording observations about the natural world. A scientist or research team will always find out as much as possible about these observations that have already been made before beginning any laboratory investigations. There are two main reasons for this: it avoids wasting time and money repeating things that have already been tried, and examining the facts may suggest the kind of experiment which is needed.

2. *The hypothesis*. From the data base, Eratosthenes arrived at a possible or tentative explanation for what was known. The explanation, in fact, turned out to be correct. Even if it hadn't, though, it would still have provided a basis for the experiment that was being planned. This tentative explanation is called the hypothesis. Often, when scientists arrive at a hypothesis, they realize that other facts that they already know make it more likely to be correct. Eratosthenes realized that observations made of ships or land appearing or disappearing over the horizon could also be explained by a curved Earth.

3. *The prediction*. From the hypothesis, scientists predict the outcome of a specific experiment which they have the expertise and the resources – equipment, time, manpower – to do.

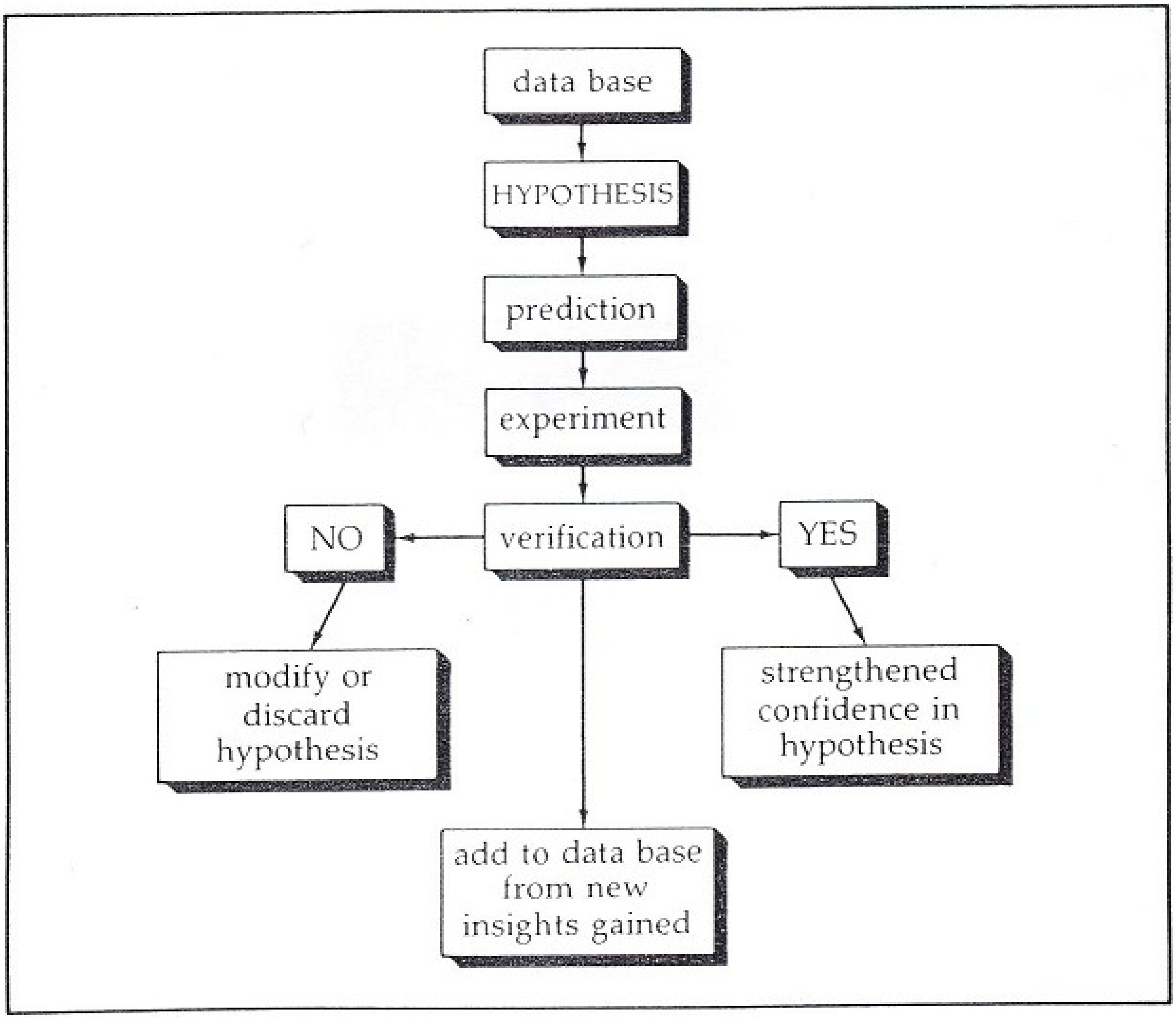
4. *The experiment*. It may seem odd that the prediction in the cycle of proof comes ahead of designing the experiment. In fact, both will usually be in the scientist's mind at the same time.

5. *Verification*. To verify something means to find out whether it is true or not. In science, the results of an experiment usually show whether or not a prediction was correct. If, as in our example, things turn out much as had been expected, scientists come away with strengthened confidence in the original hypothesis. They still recognize that it might not be correct, but their work has increased the likelihood that it is. Each experiment that tests the hypothesis and verifies it strengthens it further. Eratosthenes' prediction was further verified by the circumnavigation of the globe and last century by observations from satellites.

Often, though, a prediction turns out to be wrong. The results of the experiment are different from what was expected. If this happens, the scientists will look closely at the way the experiment was set up and carried out. (For example, if Eratosthenes' stick in Alexandria had not cast a shadow, he would have had to check that it had been aligned correctly.) In the end, scientists have to be prepared to modify or discard a hypothesis. However, even experiments in which it is discovered that the hypothesis must be discarded are valuable since the size of the data base will have been increased.

Question: For each of the following statements, determine which part of the cycle of proof (data base, hypothesis, prediction, experiment, or verification) is demonstrated.

(a) The Earth is curved.
(b) The shadow of the Earth on the Moon is observed to be curved.
(c) The next lunar eclipse is observed.
(d) The Sun and the Moon are sometimes on exactly opposite sides of the Earth and the Earth casts a shadow on the Moon in an event called a lunar eclipse.
(e) If the Earth is curved, the shape of the shadow it casts on the Moon should be curved.



More Practice

Read the following story. Highlight or underline those sections of the story that directly refer to the steps of the cycle of proof. Mark the section(s) that refer(s) to the data base with a 1, the section(s) that refer(s) to the hypothesis with a 2, etc., as in the previous story.

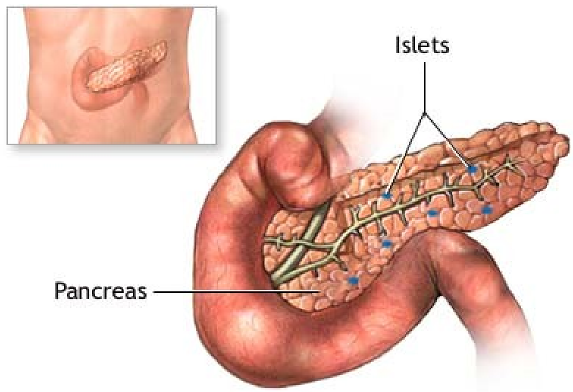
Insulin: The Work of Frederick Banting

Frederick Banting obtained his medical degree from the University of Toronto in 1916. After serving as a medical officer in the First World War, Banting went to London, Ontario, and practised as a surgeon. One of his interests was diabetes, which causes people to be abnormally thirsty and to feel more and more tired as the disease progresses. At the time, there was nothing to help diabetics. Patients slowly became thinner and thinner and eventually died.

In diabetics, the amount of glucose (sugar) in the blood reaches unusually high levels until eventually glucose appears in the urine. Clearly the diabetic is wasting glucose and is therefore not getting the full benefit from the carbohydrate part of his or her diet.

That much was known in Banting's time. And it was suspected that the pancreas, a digestive organ whose main function is to produce digestive juice to break down proteins, had something to do with diabetes since it had been discovered that when the pancreas was removed from dogs, diabetes developed. Physiologists suspected that the pancreas, in a number of areas of unknown function, known as the Islets of Langerhans, might also be responsible for the production of a hormone to control the breakdown of glucose. This supposed hormone had even been given a name: insulin. But whenever people tried to extract it, it was destroyed by the digestive juices from the rest of the pancreas.

In 1920, Banting read an article describing how tying off the tube leading from the pancreas to the intestine caused the pancreas to shrivel up. There was nothing in the article to say what happened to the Islets of Langerhans, and this gave Banting an idea for an experiment. If the pancreas was tied off, the main part would shrivel up and the digestive juices would no longer be produced, but the Islets of Langerhans, which had nothing to do with the digestive juices, would remain undamaged – and if their function were to produce insulin, they should carry on doing it and it should be possible to extract it, without it being destroyed by digestive juices, to cure diabetic patients.



In 1921, Banting persuaded Professor John Macleod at the University of Toronto to lend him a laboratory for the summer and also acquired a medical student as an assistant: Charles Best. Banting and Best tied off the pancreases of several dogs. Seven weeks later, as expected, the dogs had become quite ill. When they were killed and examined, their pancreases were found to have shrivelled up. The Islets of Langerhans, though, were undamaged, as Banting had hoped. And from these pancreases, Banting and Best extracted a hormone.

The next step was to see if this hormone controlled glucose breakdown. The two researchers removed the pancreases from more dogs, making them diabetic. Then the dogs were injected with the extracted hormone – and the dogs recovered. The injected hormone, insulin, replaced the natural insulin which the pancreas was no longer producing.

The injections worked with people too. Insulin cannot cure diabetes, but regular insulin injections, along with careful attention to diet and exercise habits, have enabled millions of diabetics to enjoy normal lives.

<u>Questions</u>

1. Explain the function of the main part of the pancreas.

2. Why did physiologists in Banting's time suspect that the pancreas had another function as well?

3. What name was given to the parts of the pancreas whose function was not known at that time?

4. What is the function of these parts, verified by Banting and Best?

5. What does the insulin that is taken by diabetics do?