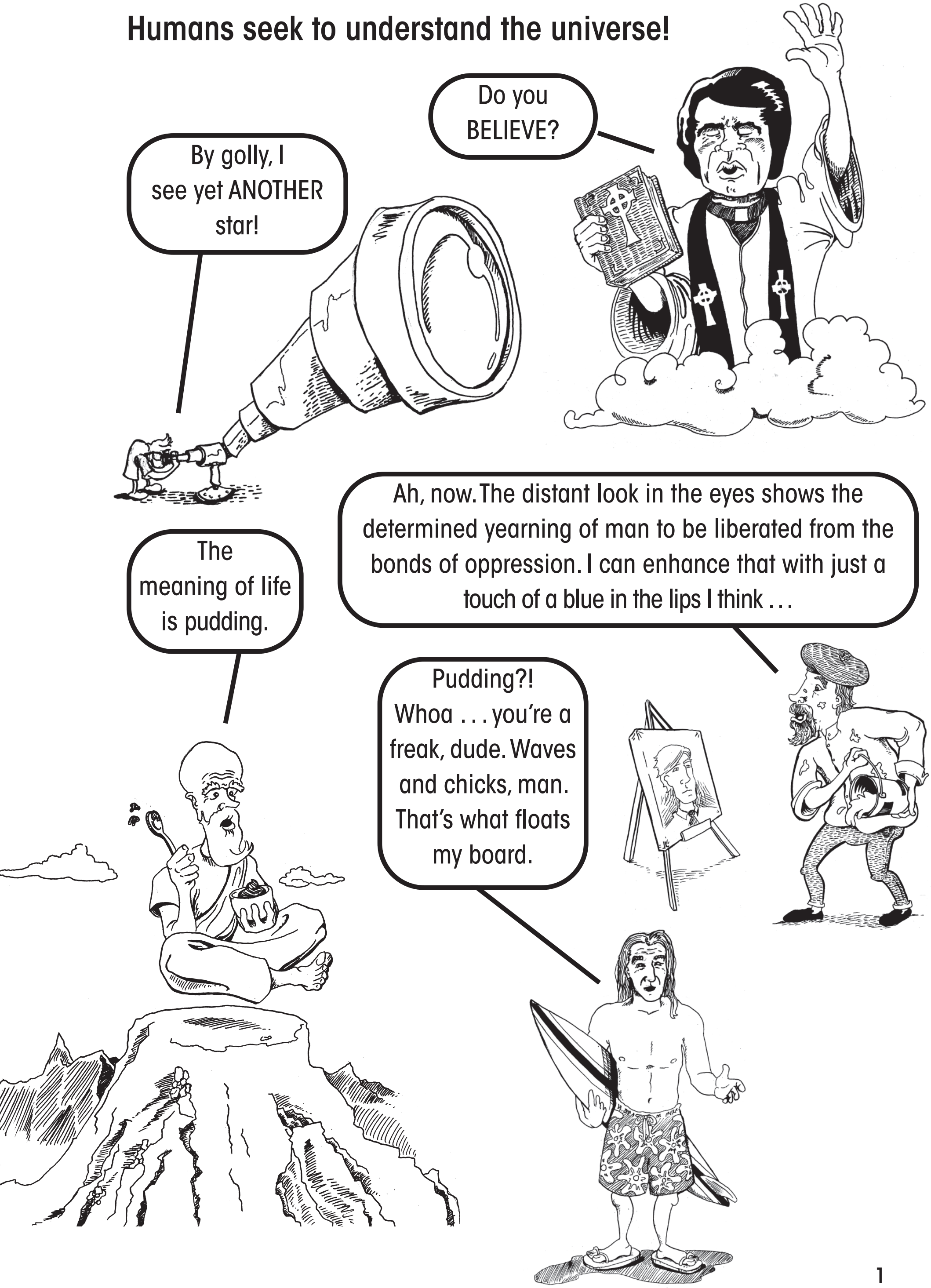
Chapter 1

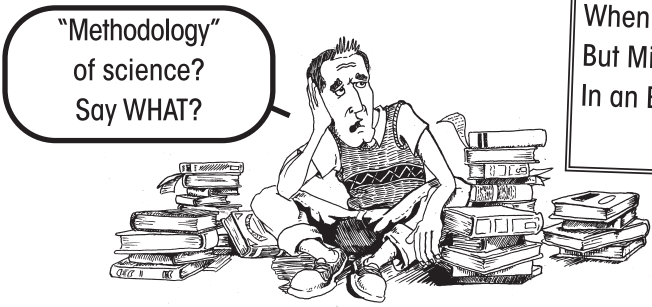
Science and the Human Bias

Humans seek to understand the universe!

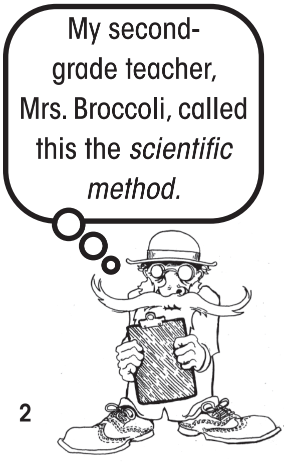


Religion is based on faith. Art is based on aesthetics. While both religion and art can provide insight into the human condition, the methodology of science is unique in that it bows to observations. Ideas that are not consistent with what we see in nature under controlled and repeatable circumstances are *thrown out*!

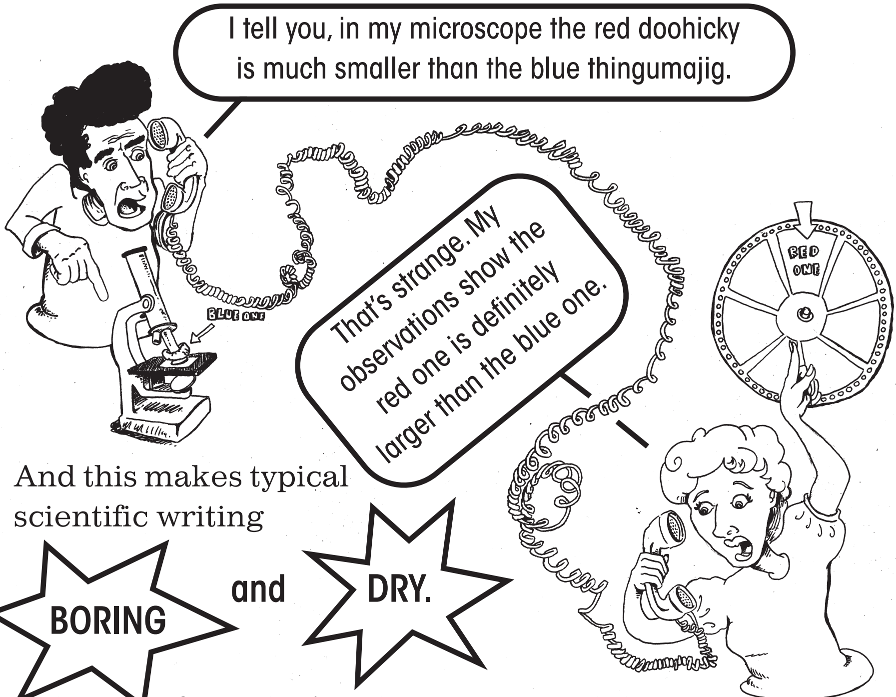
> "Faith" is a fine invention
> When Gentlemen can see,
> But Microscopes are prudent
> In an Emergency.
> — Emily Dickinson



In science a person looks at something and makes a hypothesis (or theory) about how it works. Then they design an experiment to test the hypothesis. After doing the experiment, the person modifies or discards the theory depending on the results of the experiment. This process repeats, and our scientific understanding of the phenomenon evolves.



Communication, honesty, and reproducibility of observations lie at the core of what makes science work. Experimental results must be conveyed to others unambiguously and in detail so that others can reproduce the experiment.

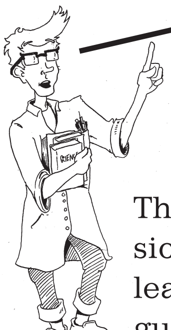


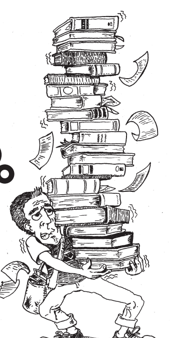
And this makes typical scientific writing

BORING and **DRY.**

If you don't believe that, read this:

> **This paper describes the measurement of the energy dependence of elliptic flow for charged particles in Au+Au collisions using the PHOBOS detector at the Relativistic Heavy Ion Collider (RHIC). Data taken at collision energies of $\sqrt{s_{NN}}$ = 19.6, 62.4, 130 and 200 GeV are shown over a wide range in pseudorapidity. These results, when plotted as a function of $\eta' = |\eta| - y_{beam}$, scale with approximate linearity throughout η', implying no sharp changes in the dynamics of particle production as a function of pseudorapidity or increasing beam energy.**





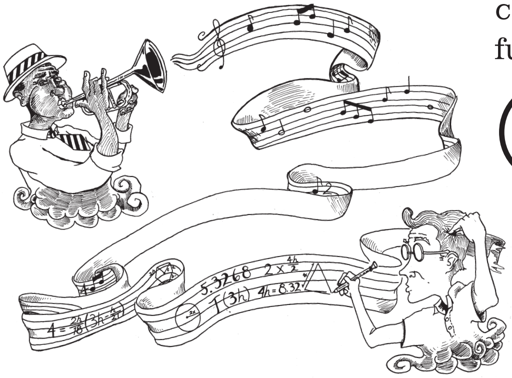
There's no room for ambiguity and confusion in scientific communications. This leads to a precise, layered, specialized language—or lingo—in each area of science.

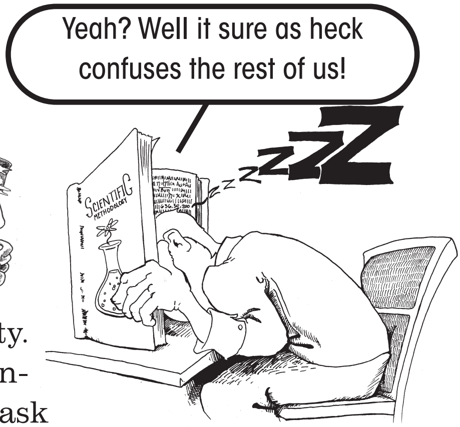
Also, this desire for unambiguous clarity, along with the basic quantitative nature of many measurements, leads to the heavy use of mathematics in science.

> Mathematics is a more powerful instrument of knowledge than any other that has been bequeathed to us by human agency. —René Descartes

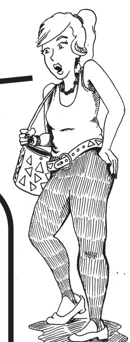
Music communicates . . . but it evokes different feelings in different people.

Mathematics and very precise language allow scientists to communicate with as little confusion as possible.

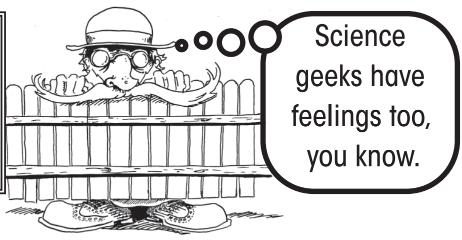




There's more to it than clarity. Mathematics and layers of concepts often lead to the ability to ask questions and have insights that are not possible otherwise.



> The most remarkable discovery made by scientists is science itself. —Gerard Piel



What is the human bias?

Natural human tendencies

Simple mistakes

In spite of scientists' attempts to make unambiguous measurements, human judgment and intuition often comes into play.

Scientists sometimes stop looking for errors in an experiment or data analysis when they get the answer they expect to find, yet they look very hard for problems if they see something unexpected.

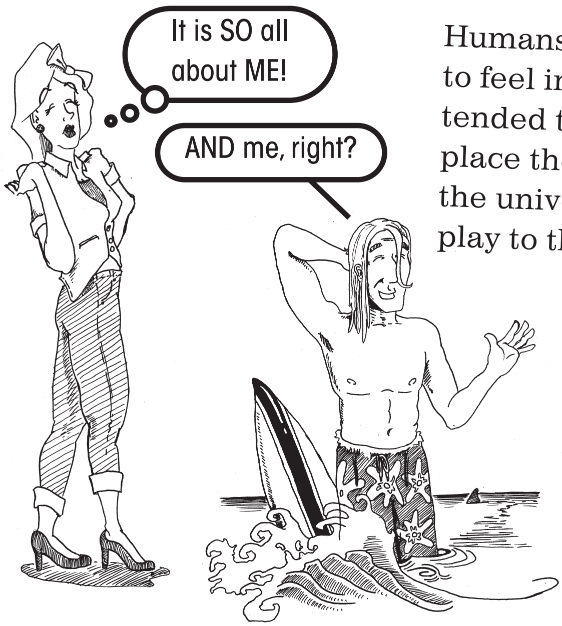
> An expert is a man who has made all the mistakes which can be made in a very narrow field. — Niels Bohr

The limitation of experience

Our senses, intuition, and tendency to interpret data are tuned to times and distances and speeds and sizes that are commonly encountered. This is what we know. Our expectations are biased toward the realm of our experience. Every time we create a new technology that allows us to see farther, smaller, or faster things we are forced to expand our minds to encompass the unexpected.

Anthropocentric and geocentric ideas

Humans have always wanted to feel important and have tended to like ideas that place them at the center of the universe. Religions often play to this desire.

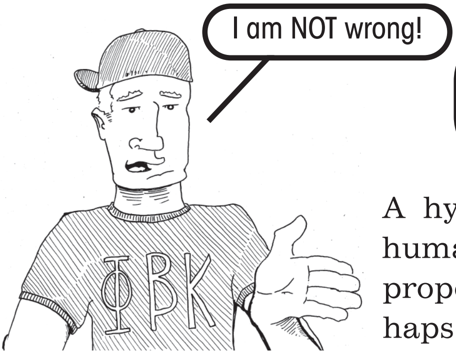


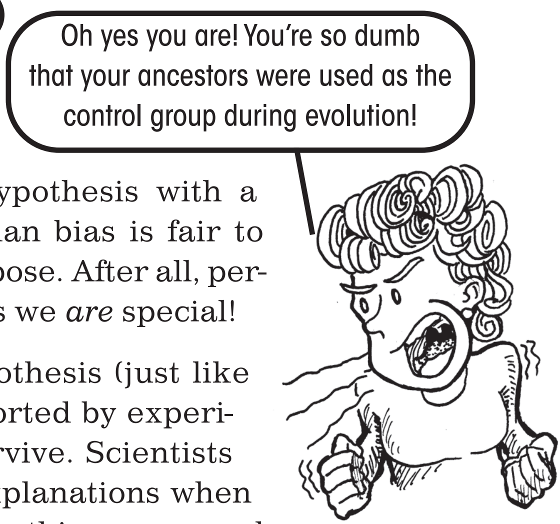
Nature doesn't seem to have the same hang-up.

Overcoming the human bias

The methodology of science tends to push us beyond the human bias.

Experimental results are shared and experiments are repeated. This leads to the constructive and frank interchange of ideas and the correction of earlier mistakes.



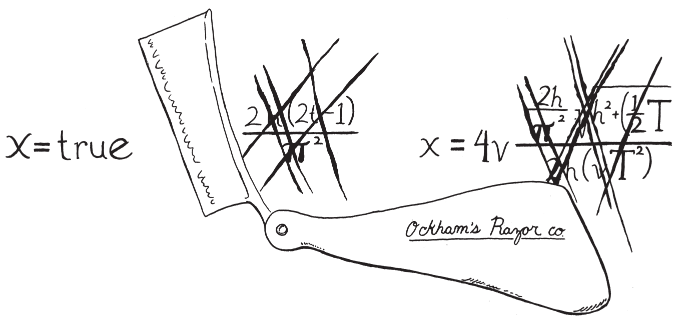


A hypothesis with a human bias is fair to propose. After all, perhaps we *are* special!

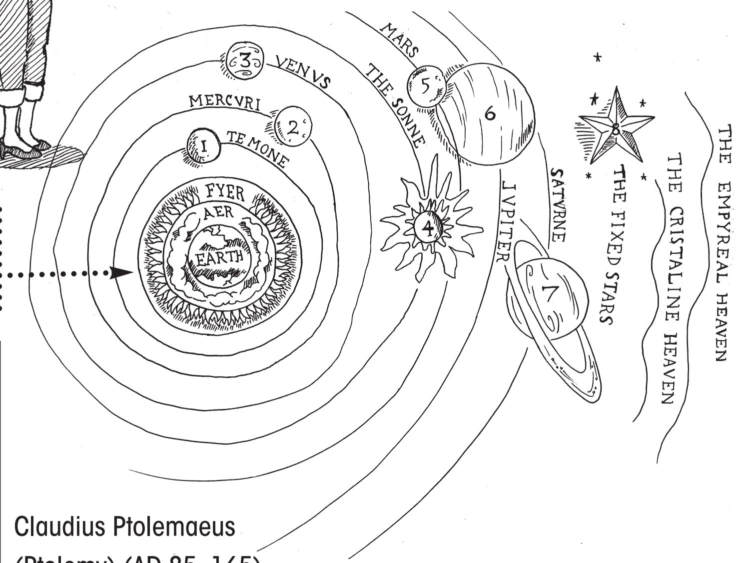
But, in science, that hypothesis (just like any other) must be supported by experimental data if it is to survive. Scientists tend to prefer simpler explanations when given a choice and all other things are equal.

As strange as it may seem, aesthetics does have a place in science. Science has an artistic side. A critical part of the methodology of science is known as Ockham's razor—when choosing between different theories that describe the data, the simplest is often the best.

> Numquam ponenda est pluralitas sine necessitate.
> (Plurality is never to be posited without necessity.)
> —William of Ockham



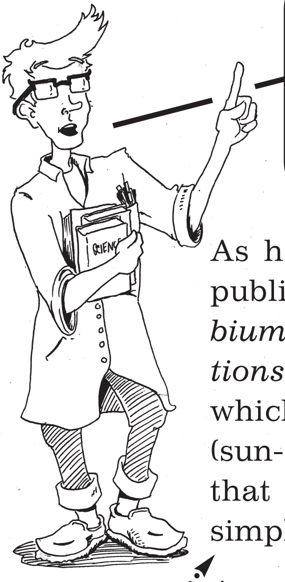
The progression of Man's view of earth's place in the cosmos is a good example of science overcoming the human bias.



Claudius Ptolemaeus (Ptolemy) (AD 85–165)

The most widely held view of cosmology through the Middle Ages was that catalogued by the Egyptian astronomer Ptolemy in his book *Almagest,* written in AD 150. The Ptolemaic universe contained many elements proposed long before his time by others, such as Aristotle and followers of Pythagoras. In Ptolemy's view, the sun, moon, stars, and five known planets move around the earth on a complex system of nested, rotating transparent (or crystalline) spheres and circles within circles. Because the planets, sun, and moon each have unique motions in the sky relative to the stars, the complicated multishell and circle-within-circle arrangement was necessary in order for the model to agree with observations of the heavenly bodies.

Then came along a Prussian astronomer (born in what is now Poland), named Nicolaus Copernicus (1473–1543), and he . . .



As he neared death, Copernicus published *De revolutionibus orbium coelestium (On the Revolutions of the Celestial Spheres),* which presented a heliocentric (sun-centered) view of the universe that was eventually shown to be simpler than Ptolemy's cosmology.

Humans less important (moved from center of universe)

Simplicicity (Ockham's razor in action)

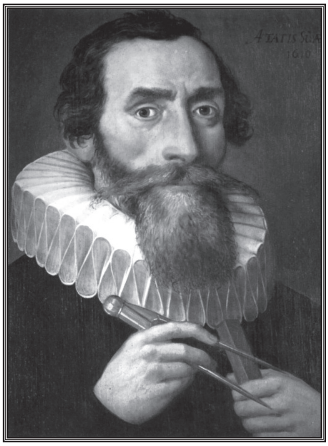
A man born shortly after the death of Copernicus, Danish astronomer Tycho Brahe, made very careful measurements of the motion of the heavenly bodies—much more accurate and precise than were available before. Brahe created a cosmological model where the sun and the moon moved in circles about the earth while the planets moved in circles about the sun.

Technology improves observations

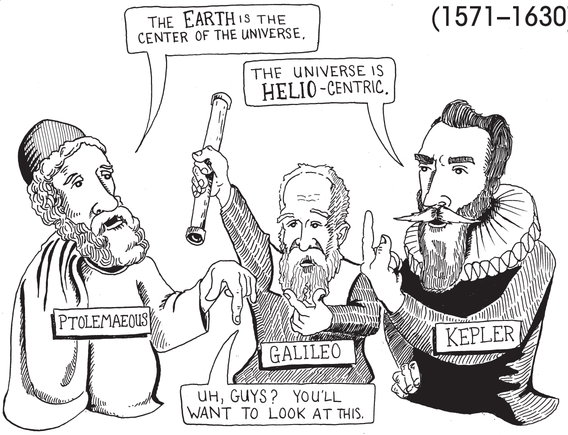
Old models inconsistent with observations thrown out as new model brought in

Armed with Brahe's data, a German astronomer and mathematician named Johannes Kepler—who had been an assistant to Brahe and "appropriated" his data upon Brahe's death—pursued his study of Brahe's data and his own observations and

To create new model, the fundamental biases long held dear are overthrown (e.g., movement of planets in circles and spheres tossed out because ellipses fit the data) discovered that a heliocentric system with the planets having slightly elliptical orbits was best able to describe the data. He developed three laws of planetary motion that eventually were explained by Isaac Newton and his theory of gravity.



Johannes Kepler (1571–1630)



The final blow against the Ptolemaic/geocentric universe came in 1610, when an Italian named Galileo Galilei used a new device—a telescope—to observe the phases of Venus. The exhibition of phases by Venus was strong evidence that Venus orbited the sun.

> To know that we know what we know, and to know that we do not know what we do not know, that is true knowledge. —Copernicus

The search for simplicity and consistency in experimental observations coupled with more and better observations allowed mankind to overthrow deeply held convictions about the structure of the universe.

The struggle against the human bias continues to this day. As we have expanded our horizons to see things vastly smaller/faster/larger/farther than ever before, we have been forced to confront preconceptions born of the human experience and create wholly new ways of looking at the world around us. There is nothing quite as strange and exciting as the reality show of our universe.

This book describes the crazy, revolutionary theories of relativity and quantum physics and shows how these ideas have led to amazing advances in our understanding of the universe.