This Will Make You Smarter

New Scientific Concepts to Improve Your Thinking

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POWERS OF 10

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An important part of my scientific toolkit is how to think about things in the world over a wide range of magnitudes and time scales. This involves, first, understanding powers of ten; second, visualizing data over a wide range of magnitudes on graphs using logarithmic scales; and third, appreciating the meaning of magnitude scales, such as the decibel (dB) scale for the loudness of sounds and the Richter scale for the strength of earthquakes.

This toolkit ought to be a part of everyone's thinking, but sadly I have found that even well-educated nonscientists are flummoxed by log scales and can only vaguely grasp the difference between an earthquake of 6 on the Richter scale and one of 8 (a thousand times more energy released). Thinking in powers of 10 is such a basic skill that it ought to be taught along with integers in elementary school.

Scaling laws are found throughout nature. Galileo in 1638 pointed out that large animals have disproportionately thicker leg bones than small animals to support the weight of the animal. The heavier the animal, the stouter their legs need to be. This leads to a prediction that the thickness of the leg bone should scale with the 3/2 power of the length of the bone.

Another interesting scaling law is that between the volume of the brain's cortical white matter, corresponding to the long-distance wires between cortical areas, and the gray matter, where the computing takes place. For mammals ranging over 5 orders of magnitude in weight—from a pygmy shrew to an elephant—the white matter scales as the 5/4 power of the gray matter. This

means that the bigger the brain, the disproportionately larger the fraction of the volume taken up by cortical wiring used for communication compared to the computing machinery.

I am concerned that students I teach have lost the art of estimating with powers of 10. When I was a student, I used a slide rule to compute, but students now use calculators. A slide rule lets you carry out a long series of multiplications and divisions by adding and subtracting the logs of numbers; but at the end you need to figure out the powers of 10 by making a rough estimate. A calculator keeps track of this for you, but if you make a mistake in keying in a number, you can be off by 10 orders of magnitude, which happens to students who don't have a feeling for orders of magnitude.

A final reason why familiarity with powers of 10 would improve everyone's cognitive toolkit is that it helps us comprehend our life and the world in which we live:

How many seconds are there in a lifetime? 10^9 sec

A second is an arbitrary time unit, but one that is based on our experience. Our visual system is bombarded by snapshots at a rate of around three per second, caused by rapid eye movements called saccades. Athletes often win or lose a race by a fraction of a second. If you earned a dollar for every second in your life, you would be a billionaire. However, a second can feel like a minute in front of an audience, and a quiet weekend can disappear in a flash. When I was a child, a summer seemed to last forever, but now the summer is over almost before it begins. William James speculated that subjective time was measured in novel experiences, which become rarer as you get older. Perhaps life is lived on a logarithmic time scale, compressed toward the end.

What is the GDP of the world? $\$10^{14}$

A billion dollars was once worth a lot, but there is now a long list of multibillionaires. The U.S. government recently stimulated the world economy by loaning several trillion dollars to banks. It is difficult to grasp how much a trillion dollars ($\$10^{12}$) represents, but several clever videos on YouTube (key words: trillion dollars) illustrate this with physical comparisons (a giant pile of $100 bills) and what you can buy with it (ten years of U.S. response to 9/11). When you start thinking about the world economy, the trillions of dollars add up. A trillion here, a trillion there, pretty soon you're talking about real money. But so far there aren't any trillionaires.

How many synapses are there in the brain? 10^{15}

Two neurons can communicate with each other at a synapse, which is the computational unit in the brain. The typical cortical synapse is less than a micron in diameter (10^{-6} meter), near the resolution limit of the light microscope. If the economy of the world is a stretch for us to contemplate, thinking about all the synapses in your head is mind-boggling. If I had a dollar for every synapse in your brain, I could support the current economy of the world for ten years. Cortical neurons on average fire once a second, which implies a bandwidth of around 10^{15} bits per second, greater than the total bandwidth of the Internet backbone.

How many seconds will the sun shine? 10^{17} sec

Our sun has shined for billions of years and will continue to shine for billions more. The universe seems to be standing still during our lifetime, but on longer time scales the universe is filled with events of enormous violence. The spatial scales are also immense. Our space-time trajectory is a very tiny part of the universe, but we can at least attach powers of 10 to it and put it into perspective.

LIFE CODE

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Everyone is familiar with digital code, the shorthand IT. Soon all may be discoursing about life code.

It took a while to learn how to read life code; Mendel's initial cookbook was largely ignored. Darwin knew but refused for decades to publish such controversial material. Even DNA, a term that now lies within every cheesy PR description of a firm, on jeans, and in pop psych books, was largely ignored after its 1953 discovery. For close to a decade, very few cited Watson and Crick. They were not even nominated, by anyone, for a Nobel until after 1960, despite their discovery of how life code is written.

First ignorance, then controversy, continued dogging life code as humanity moved from reading it to copying it. Tadpoles were cloned in 1952, but few focused on that process until 1997, when the announcement of the cloning of Dolly the sheep begat wonder, consternation, and fear. Much the same occurred with in-vitro fertilization and Louise Brown, a breakthrough that got the Nobel in 2010, a mere thirty-two years after the first birth. Copying genes of dozens of species, leading to hundreds of thousands of almost identical animals, is now commonplace. The latest controversy is no longer "How do we deal with clones?" but "Should we eat them?"

Much has occurred as we learned to read and copy life code, but there is still little understanding of recent developments. Yet it is