Chapter 1: Numbers

Section 7 Part 1: Units & Standards

Woe to those who give short weight!

-The Holy Quran

This section is about standard units for measurements – meters, degrees Celsius, Joules ... We start learning the standards of our culture shortly after we’re born: the words, the ways to pronounce them, how to behave towards elders, how to dress and act in public. But also, the names of numbers, letters, characters and kanji.

While many of these are universal – all cultures have words for white and red, for example (see p80) but meaning differs amongst cultures. Americans associate white with purity and red with danger, while Chinese associate red with good fortune (Figure 66) and white with death. Researchers now believe that perception of basic colors is built into our brains, but that culture tells us what to do with those colors.

In the same way, both our society and the way we interact with the world tell us what to do with numbers. The Nootka, a fishing culture on Vancouver Island, use month names like Eneecoresamilth, salmon fishing moon (see p80). The name reflects how Nootka culture interacts with the world.

Religions tell a different part of the story. Chinese New Year, Passover, Easter, Ramadan and Holi are all lunar celebrations: all are associated with the appearance of a full or new moon, and all occur on a different days or months as the years change. Even though the date of these holidays changes from year to year, lunar holidays are a sophisticated solution to scheduling public holidays before instantaneous communications: they work because everyone can look and see the moon (see p80).

So, standards have to be accessible: Figure 67 shows British standards for lengths, set in a public square outside Greenwich Observatory. Along these lines, a sixteenth-century German town defined the ‘foot’ as follows:

Stand at the door of a church on a Sunday and bid 16 men to stop, tall ones and small ones, as they happen to pass out when the service is finished; then make them put their left feet one behind the other, and the length thus obtained shall be a right and lawful rood to measure and survey the land with, and the 16th part of it shall be the right and lawful foot (see p800).
Polynesian men working together to make a boat measure off distances using the length of their finger joints. In pre-revolutionary France, over 700 local French units existed, with some 250,000 different measures (see p81).

Each of these ways of measuring works in a context: in surveying one town, a local measure of the foot is simple and useable. Boats, held together with lashed reeds, are flexible enough to allow small variations in lengths. We saw this in Babylonian astronomy, p24: to chart the position of the planets, astronomers used an easily accessible reference, the first appearance of a planet on the horizon. Again, in pre-revolutionary France, plots of land might be measured by their productivity or the difficulty in working the land; see also Egyptian techniques for taxing land, p55. But these kinds of standards work less well when ships are made of metal plates. They also don’t travel very well: as French villages became connected into an empire, traders needed long tables of equivalents between measures, and the empire had difficulty assessing taxes.

But enforcing standard measure across an empire is difficult: Figure 68 shows the Babylonian Sun God Shamash, holding a standard measuring rod and a coiled rope, both used in surveying land. In the Hebrew Holy Bible, Leviticus 19:36, we read:

“You are to have honest balances, honest weights, an honest dry measure, and an honest liquid measure; I am Yahweh your God, who brought you out of the land of Egypt.’

The suggestion in these quotations, and in the header to this Section, is that standards are a basic form of honesty necessary for public order. What better way to enforce standards than to connect them with the law of God?

Even today, standards are a serious issue. In a hospital,

Clinical error and negligence are responsible for disabling injuries in about 1 in 25 hospital admissions. Most of these injuries are caused by adverse drug events [...] Converting among ratios, percentages, international units, mols, micrograms, and milligrams causes substantial difficulty (see p80).

Here’s an example anyone might come across (see Figure 69): the illegal psychoactive drug MDMA. It has an average half-life of 8 hours in the body, and drug tests can detect it in blood concentrations as low as 500 nanograms per milliliter. An average amount of blood is 5.9 liters, and average dose is 120 milligrams. How long before MMDA is undetectable?
You could easily spend ten minutes converting these different measures into only one standard unit.

Modern scientific units are based on the metric system, first introduced in post-revolutionary France in the late 1700’s. The standardization of measures was taken up by the (formerly Royal) Academy of Science; revolutionary principles and Enlightenment ideals suggested standards should be based on nature itself, and would then be universal. Eventually, four major principles were set:

i) The unit of length should be based on a fraction of the circumference of the earth – measured on a circumference that passed through France (of course).

ii) The standards should be linked together into one coherent system: for example, length is measured in meters, so the units for area have to be square meters.

iii) Numbers should be expressed in base ten.

iv) Fractions and multiples of basic units should be named systematically, using Greek prefixes: milli-meter, mega-watt, etc. These are to denote units in ranks of 10, 10^2, . . .

Little was natural or universal about these principles (see p81); many scientists argued for using a pendulum to measure lengths: the time for a pendulum to go a full cycle is

\[ t = \sqrt{\frac{L}{g}} \]

Here g is the acceleration of gravity, and L is the length of the pendulum. Now set the meter to that length which lets the pendulum go through a full cycle in exactly one second. Unfortunately, g varies with one’s position on the earth, though this wasn’t well understood at the time (see Figure 70).

Other objections were that a base eight system (instead of a decimal system) would allow shopkeepers to easily compute half, then half again, and half again. A base twelve allows halves, thirds, sixths. And, why Greek names? (“These names are novel and unintelligible to the large majority of our citizens, are not necessary for the maintenance of the Republic.”)

All of these early standards were based on measures of ‘natural’ objects; the kilogram was based on the weight of water at a given temperature, and this standard was converted into an equivalent weight of a platinum-iridium bar kept in a bank vault in Paris. What happens next is told in Rachel Courtland’s article The Kilogram, Reinvented (see p81):
Once every few decades, a scientist plucks the cylinder from its perch with chamois-leather-padded pincers, rubs its surface with a cloth soaked in alcohol and ether, and steam-cleans it. Then he puts the prototype in a precise balance that compares it to the bureau’s official copies, which are in turn compared to copies kept by member countries. And thus the prototype mass trickles down to set the standard for the rest of the world.

The system has been far from seamless. When the cylinder was last removed from the vault in 1988, the bureau’s metrologists were disappointed to discover that its mass and those of its official copies had drifted apart by as much as 70 micrograms since 1889.

The metric system was adopted on 23 September 1801 (or, speaking of standards, the Revolutionary government gave the date as 1 vendémiaire an X); many businesses covertly kept the old measures. Government documents, as well as legal, military and engineering documents were required to be submitted in metric units, though for some time dual systems were used in the government. And, of course, public standards needed to be publicly available; the Agency of Weights and Measures printed seventy thousand conversion tables. Mass production of meter sticks was more difficult, and eventually the Committee for Public Safety turned the task over to the Atelier de perfectionnement – an armory specializing in mass production of interchangeable parts for rifles (see p81). In France, use of the old units only died out in the early 1900’s.

Internationally, the United States still uses British units. In 1999, a joint American-British space probe crashed into the surface of Mars because flight controllers had no real idea where the probe was. Software designers in Britain used meters; those in the United States used feet, and the ’orbiter’ entered too deeply into the Martian atmosphere and broke up. The NASA report (see p81) noted that metric units were specified in the contract; that NASA had a history of reusing old, undocumented code, and that two navigators had reported problems but were ignored.

Standards alone accomplish little; only people can make them work.
Notes for Chapter 1 Section 7 Part 1: Units & Standards

p76 The universality of certain colors, called focal colors, contradicts theories of cultural and physical relativism. Brent Berlin and Paul Kay looked at 20 oral world languages, and

"Berlin and Kay found out that people focus certain points in the color continuum as a kind of orientation. Such reference points or 'best examples' were called 'foci'. Focal colors had not only been detected in English but also in the remaining 19 languages (Berlin & Kay, Basic Color Terms: Their Universality and Evolution, Berkeley: University of California Press 1969).

Eleanor Rosch went further, using experiments to determine the physical and psychological role of focal colors:

Rosch was able to find out that focal colors are more perceptually salient than non-focal ones (Rosch, Eleanor (1973), Natural Categories, Cognitive Psychology 4: 328-350). This cognitive salience is probably not anchored in language but reflects certain physiological aspects of [...] perspective mechanisms. Later, she coined the term 'prototype' instead of 'focal'.

Quotations are from http://www.glottopedia.org/index.php/Focal_Colors

p76 Nootka numbers from William J. Folan

p76 Even in a lunar calendar, deciding the exact day the moon is full or new has to be standardized. In Islam, this is the duty of the Imam. In a small village in Africa, it would be the duty of the Chief Priest. Chinua Achebe, the Nobel prize-winning author, describing the process in his novel Arrow of God:

‘The moon he saw that day was as thin as an orphan fed grudgingly by a cruel foster-mother. He peered more closely to make sure he was not deceived by a feather of cloud.’

p76 The quotation defining the foot is from Jacob Koebel,
Geometrei. Von künstlichem Feldmessen und absehen.


Part of the issue was that powerful political forces were at work. The Ministry of Finance wanted to compute taxes for the entire country; scientists at the Academy received large grants to perform the difficult and inaccurate job of measuring the circumference of the earth. But, in the end . . . opposition was so intense that the Emperor Bonaparte rescinded the system, and it was delayed for decades. The metric day, the metric week (a ten day week, with nine work days and one day of rest) and the metric year never caught on.


Quotation from Rachel Courtland’s article is from http://spectrum.ieee.org/consumer-electronics/standards/the-kilogram-reinvented
