

## What Are the Units, and Why? Review of *The Science of Measurement: Taking the Measure of the World*

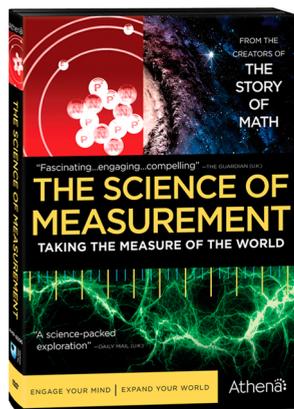
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**Science of Measurement: Taking the Measure of the World**, presented by Marcus du Sautoy. Athena Learning: Silver Spring, Maryland, 2013. 3 episodes, 177 min. DVD. \$18.

When you hop the Atlantic with a BBC program, the odds are good that someone will want to rename it for an American audience. Which is too bad, in this case, because the British title for Marcus du Sautoy's three-parter on measurement is closer to the mark: *Precision: The Measure of All Things*. I've been thinking about precision lately, because 32 years after a college boyfriend tried to get me to read Feynman's physics lectures,<sup>1</sup> I'm finally capable of reading them. And not only are they wonderful lectures, but along the way Feynman says all kinds of things that would have helped me immensely in high school. Have a look at this, for instance, from his chapter on motion:<sup>1</sup>

*The theory of relativity shows that our ideas of space and time are not as simple as one might think at first sight. However, for our present purposes, for the accuracy that we need at first, we need not be very careful about defining things precisely. Perhaps you say, 'That's a terrible thing—I learned that in science we have to define everything precisely.' We cannot define anything precisely! If we attempt to, we get into that paralysis of thought that comes to philosophers, who sit opposite each other, one saying to the other, "You don't know what you are talking about!" The second one says, "What do you mean by know? What do you mean by talking? What do you mean by you?" and so on. In order to be able to talk constructively, we just have to agree that we are talking about roughly the same thing.*



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That's an extremely difficult idea: the idea that in science, although we aren't talking colloquially, and science's words haven't got the shifting, multiple meanings ordinary words do, science's words and ideas are not really precise. It's the idea that

we don't know scientific things exactly *even though we made up the ideas ourselves*. This can be a deeply confusing reality to confront, but it's what du Sautoy, the excitable Oxford mathematician, is talking about when he talks about the mighty, multimillennial effort to know how much there is of whatever you're looking at—and then to know it more precisely.

With du Sautoy's help, you begin to see what strange and vexing problems these are. How do you define *amount of what you're looking at*? What, as we ask students repeatedly, are the units? The end point of this series' tale is the seven fundamental SI units, from which all others can be made: the meter, kilogram, mole, second, ampere, kelvin, and candela. Meaning that the most important things to measure, by our reckoning, are length, mass, quantities of atoms, time, electrical current, heat, and light intensity. But it is in no way obvious that all of these are things to measure, let alone important things to define and fix a standard measure to, or indeed that any other physical phenomenon you care to measure might be translated into these seven. So you see the size of the job that du Sautoy has cut out for himself.

As is usual for Athena/BBC science shows, the series is a lightning tour with many familiar subplots, wonderfully engaging, well designed and well written. In each episode, du Sautoy sets up the evolution of the problems that not only showed insightful people what needed measuring, but set them urgently to inventing reasonable, then increasingly precise and standardized, means of taking those measurements. Take mass, for instance. As du Sautoy demonstrates at a street market, we're miserable at hefting an object and assessing its weight ourselves; we seem instead to be built for assessing density. A small hefty object will feel heavier to us than will a large, foamy object that weighs considerably more. If you buy and sell by weight, though, as merchants long have done, then you must be able to assess weight with fair accuracy. So trade, the story goes, drove the adoption of a measuring tool and standard unit for weight: the balance and the grain of wheat, which was not only ubiquitous but ...well, not a perfectly standard weight, but as my Northern Irish friend says, near as dammit.

But grains are bulky and you can't fit millions of them on a little balance pan; so merchants and then governments made denser equivalent measures of metal, and these became local standards, a beautiful array of which Sautoy shows us. Alas, the mad proliferation of equivalent measures also gave rise to a proliferation of cheats, also of difficulties in translating between one town's weights and another's. It took the French revolutionaries and their mania for rationality and universality to introduce a standard, scientifically devised measure of

weight: the kilogram, based on the weight of water and distressingly rational principles which were harder to implement than expected. Water is not all that simple, as it turns out, nor does it behave in the same fashion everywhere. The dream of rational measurement faltered on the rocks of available science and technology, and it was a long, hard slog across chemistry, atmospheric science, metallurgy, and continental politics before a standard kilogram measure—an actual thing, a lump of metal—was attained and welcomed.

And then it began to lose weight.

The story of “le grand K” losing infinitesimal amounts of mass, and threatening to throw us into new confusion, is the beginning of du Sautoy’s telling of a hunt for a more precise and stable way of measuring mass, based on the development of increasingly precise measurements of *other* things: electrical current, quantities of atoms, length, time. What’s remarkable throughout is how du Sautoy manages to juggle the measurements without (I think) confusing newcomers to SI units, describing the continuous push away from human-body-based measurements and toward presumed constants and universals: the size of the earth, the frequency of an atomic oscillation, the speed of light.

There’s much to love about this series. There’s the time spent with a small and admittedly odd club: measurement researchers in the United States and Europe, all of whom are working on space-shot projects aimed at a reaching a new level of precision in one unit or another. There’s the admiration of the excellent science and technology developed by amateurs: an early clock, the recognition that heat is energetic. There’s the ingenuity of combining multiple new methods of measurement to solve the problem, for instance, of weighing freight-car payloads without making the train stop to unload, then reload. There are the French scientists who waved off the Revolution and went around not caring that they looked like spies, triangulating their way along a French meridian so as to determine the circumference of the earth with some accuracy; the dismay and nausea at discovering that temperature scales are not universal, but work only over certain ranges, then distort and fall apart; the way we extend our reach in the universe, change how we live, and integrate and enrich ourselves through trade with each jump in measurement precision. Not to mention du Sautoy’s own hands-in-pockets, ticking-along, endlessly talking determination to get to one interesting spot in history, and one interesting lab, after another. But what I like best is the question du Sautoy implicitly raises about why we recognize these seven measures as fundamental, and the shock of recognizing that these measurements, and indeed our understanding of words like *length* and *time*, are approximations that can be made more precise—but precise to what limit, I do not know. The quest for precision leaves those who venture into that world looking more than a little wild-eyed, fearing the passage of cars, those precision machines, across the quiet parkland around a NIST laboratory building: the tremors might measurably disturb the massive, copper-shielded, exquisitely sensitive balance inside.

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### Notes

The authors declare no competing financial interest.

## ■ REFERENCES

- (1) Feynman, R. P.; Leighton, R. B.; Sands, M. *The Feynman Lectures on Physics*; Addison–Wesley: Boston, MA, 1964.