Science and Uncertainty

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Published online: 18 December 2018

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I have always disliked the cook-book laboratory exercises, which often have the goal to show how a procedure is done. For instance, biology students may have a laboratory exercise on polymerase chain reaction (PCR), during which they follow a list of predetermined steps in order to arrive at a nice image of well-separated bands on a gel. This is the kind of experience I had as an undergraduate student, and at that point I thought that PCR is simple to do. When a few years later I was doing my diploma study for my MSc in genetics, it took me about 2 months to produce this kind of image with the well-separated bands. I had to try a number of combinations of products and concentrations (I honestly do not remember the details, that was 20 years ago, but I remember how hard it was) in order to produce what in the past had seemed to me as easy-to-do. Therefore, the cook-book laboratory work I had undertaken as an undergraduate student had clearly misled me about how laboratory science is done.

The only exception I can think of was an undergraduate course on analytical chemistry, during which we first did a cook-book procedure in order to figure out how things work, and then in the next lab we had to apply what we had learnt in order to identify a product or estimate the concentration of a given substance. If we failed more than twice, we would have to repeat the labs! Oh well, this was tough but later I realized that this was the only experience I had that had prepared me for the difficulties of doing lab work in science. And my experiences during my MSc study convinced me that I did not have the patience required in order to devote my professional life to working in a lab. But, most crucially, it was only then that I had started to realize the level of uncertainty inherent in scientific research. Many things can go wrong and it is hard to single out the factor(s) responsible for this. But is this something that teachers teach to their students?

Several years later, while I was teaching at the IB Diploma Programme, I supervised a student who wanted to study the influence of various factors on the population growth of soil protozoa. That was a typical laboratory exercise we did at school. We took some soil, put it in a bucket with water and some nutrients, and a few days later it was full of protozoa for students at all levels to observe under the microscope and get a sense of life at the microscopic level. That student however tried to achieve this for several weeks, with no results. Nothing could be

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observed, even though he repeated the same typical procedure several times. In the meantime, the deadline for submitting his work was approaching. The only solution I could think of was to ask him to submit the results he had (nothing found) and try to explain where things went wrong. He thus devoted all of his remaining time to figure out the possible factors that could have prevented the protozoa from multiplying in the bucket. The IB examiners appreciated the effort.

How often are these issues discussed in schools? From my personal experience, I have the feeling that both teachers and students love the science of certainty that provides definitive answers and dislike the science of uncertainty where things can go wrong. In many cases of public resistance to science, such in the cases of anti-evolutionists, climate change denialists, and anti-vaxxers, it seems that the main problem is not only the lack of understanding of the relevant science, but also—and perhaps most crucially—the lack of understanding of the uncertainty inherent in science. This, of course, does not mean that science in general is uncertain. On the contrary, most of our scientific understanding is solid and robust as far as the general picture is concerned. There is no doubt that evolution and climate change are happening, or that vaccines are overall useful and safe. However, there will always be uncertainties in the details. These uncertainties motivate further research and, as Kevin McCain and I explain in an upcoming book on this topic, uncertainty actually makes science advance.

Therefore, I think that it is a top priority for science education to explain this issue in detail. People need to learn to live with uncertainty in general, and understand what risk and probabilities are about. As Gerd Gigerenzer has put it, we usually teach our students the mathematics of certainty, geometry, and not the mathematics of uncertainty, statistics. Paraphrasing him, I would argue that we also teach our students the science of certainty, which can figure out everything and provide answers to all questions, and not the science of uncertainty, which advances exactly because there will always be small details we will not be certain about and for which we will always seek answers.

Let us appreciate science for what it is and let us help our students to also appreciate it. We understand nature better and better, but there will always be open questions for us to explore. This is what makes science fascinating!

Conflict of Interest The author declares no conflict of interest.